THE PRODUCTION ENGINEER

NOVEMBER 1960

THE PRODUCTION ENGINEER

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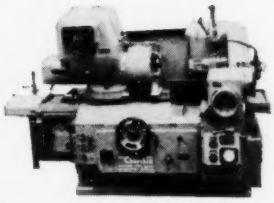

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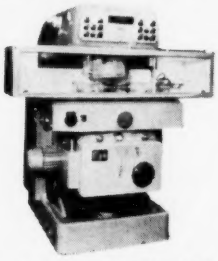

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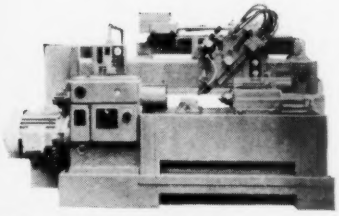

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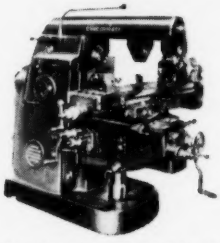

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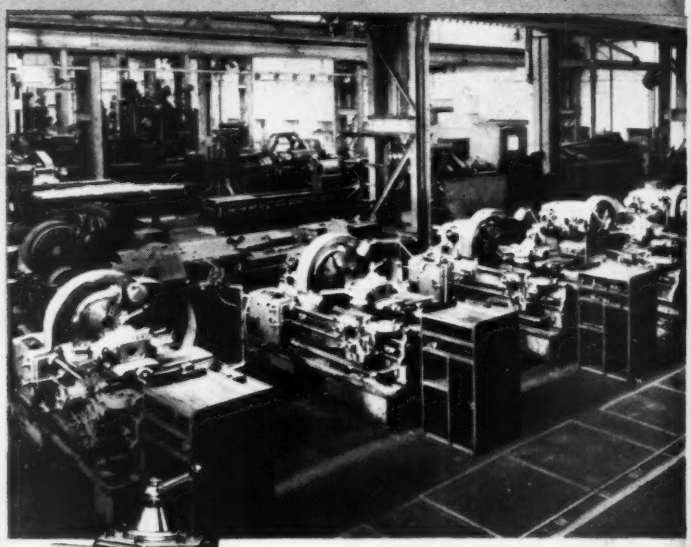

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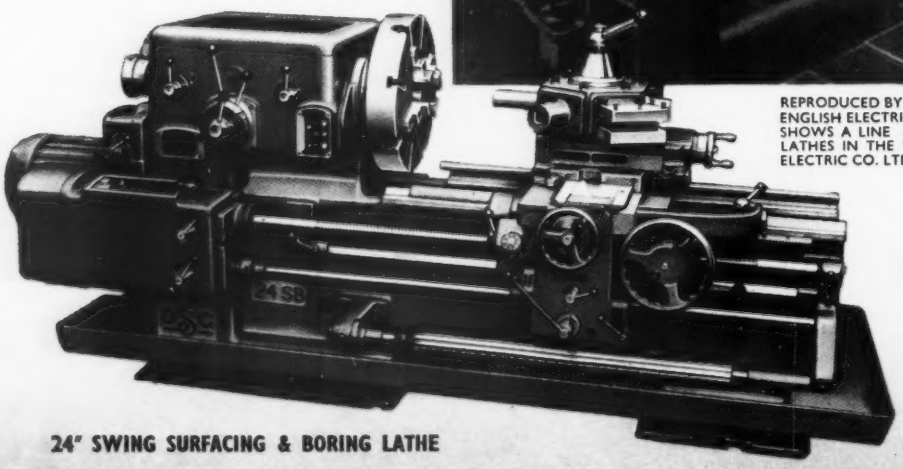

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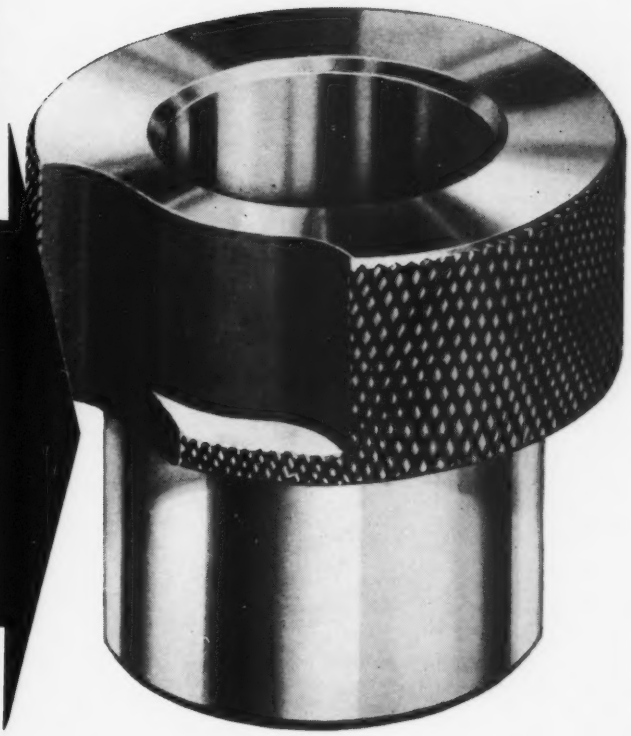

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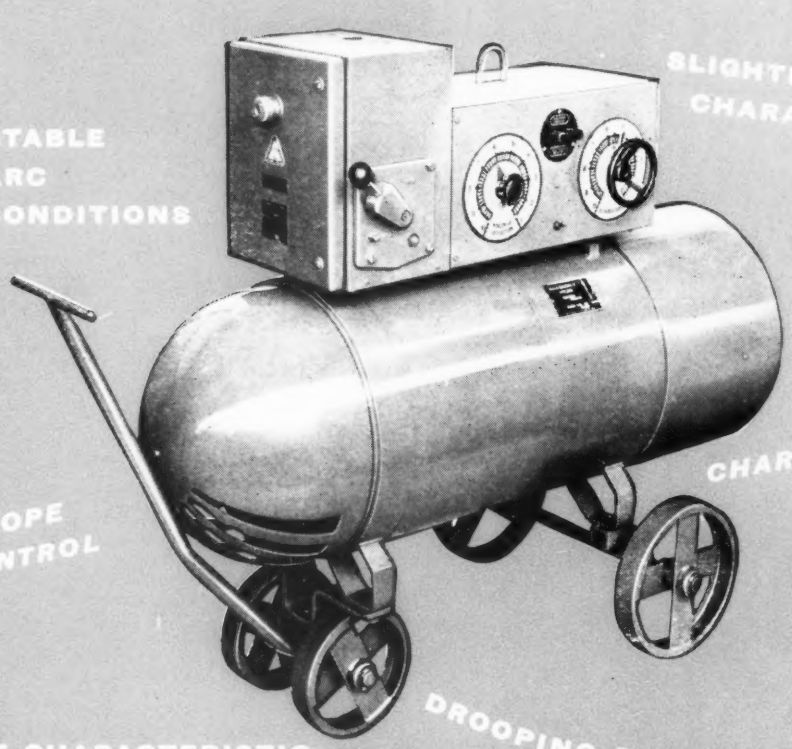

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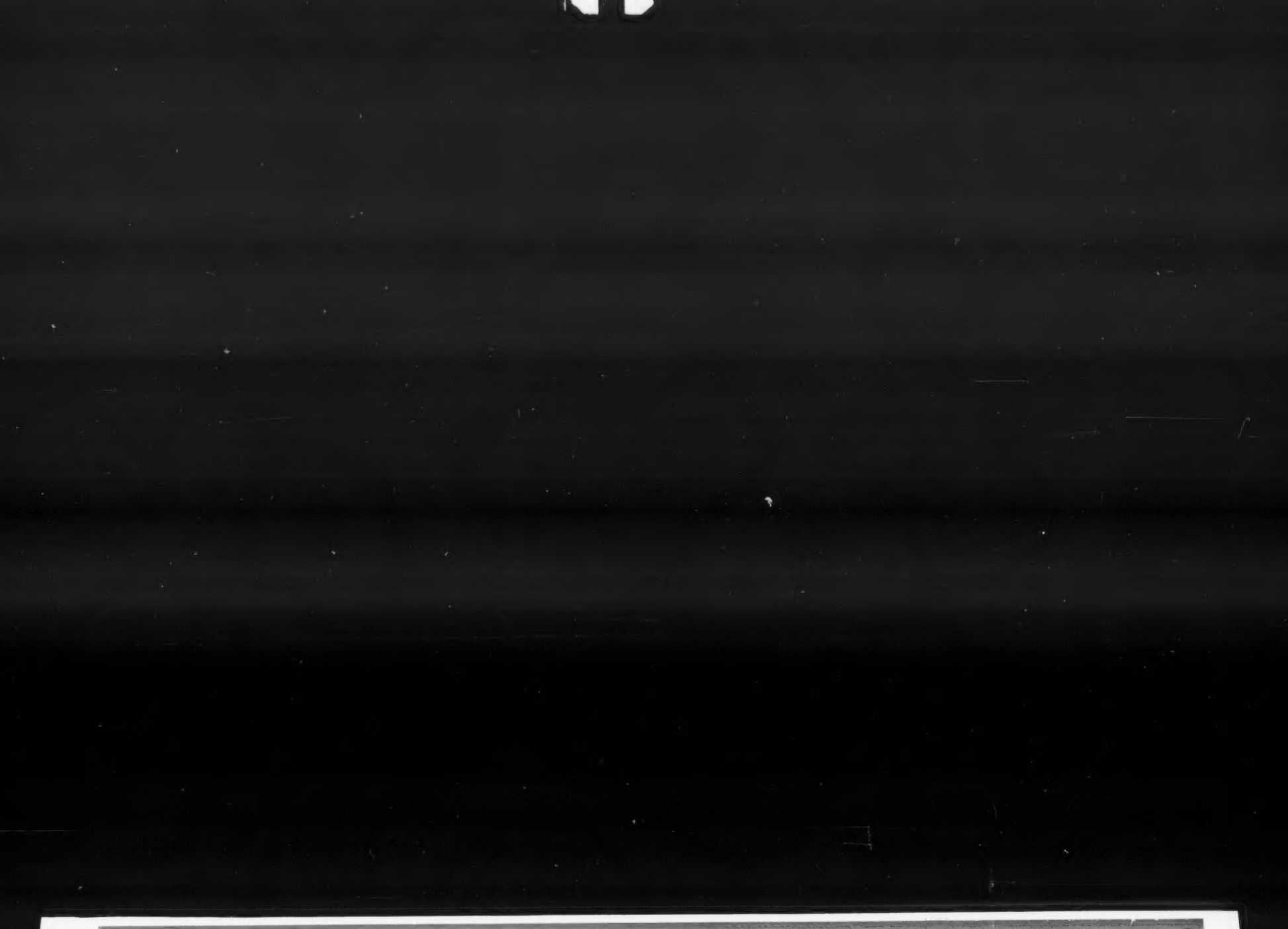

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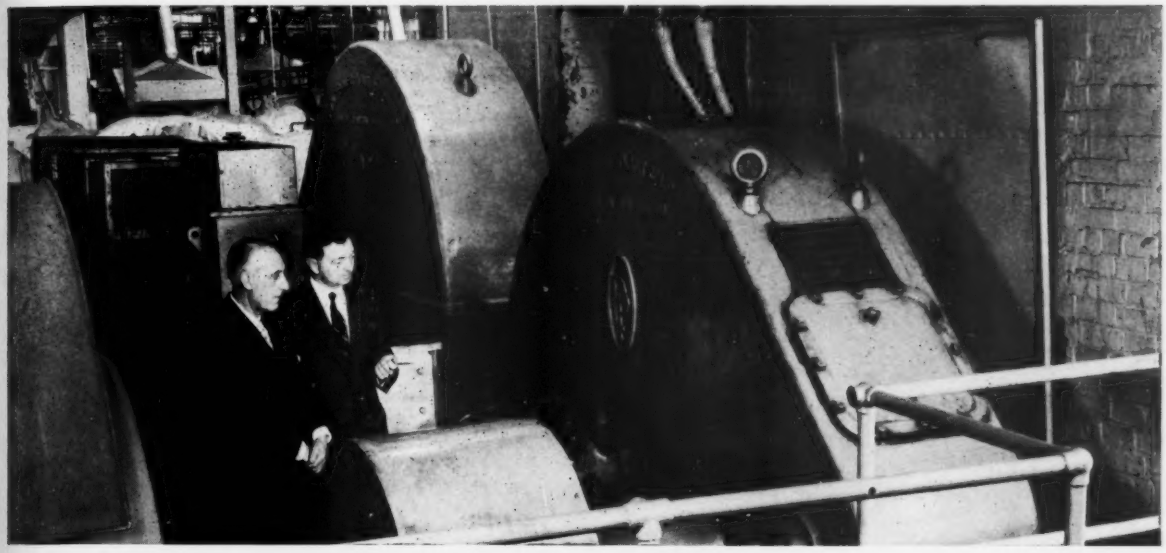

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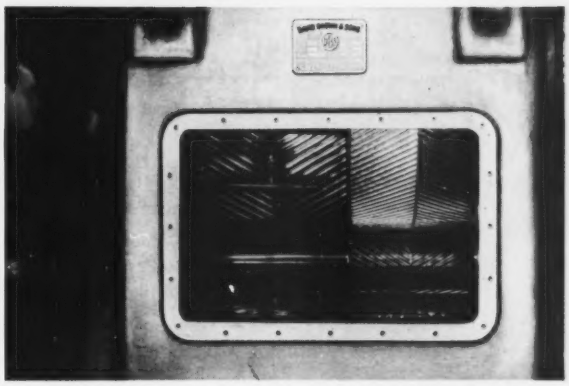

(Above) Regent Sales Engineers in the Dunlop factory, Birmingham.

(Inset) The 600 HP Double Reduction Speed Reducer in this picture at the Dunlop factory in Birmingham is driving a Mixer. Dunlop have found Regent Oil ideal for the efficient lubrication of these gears.

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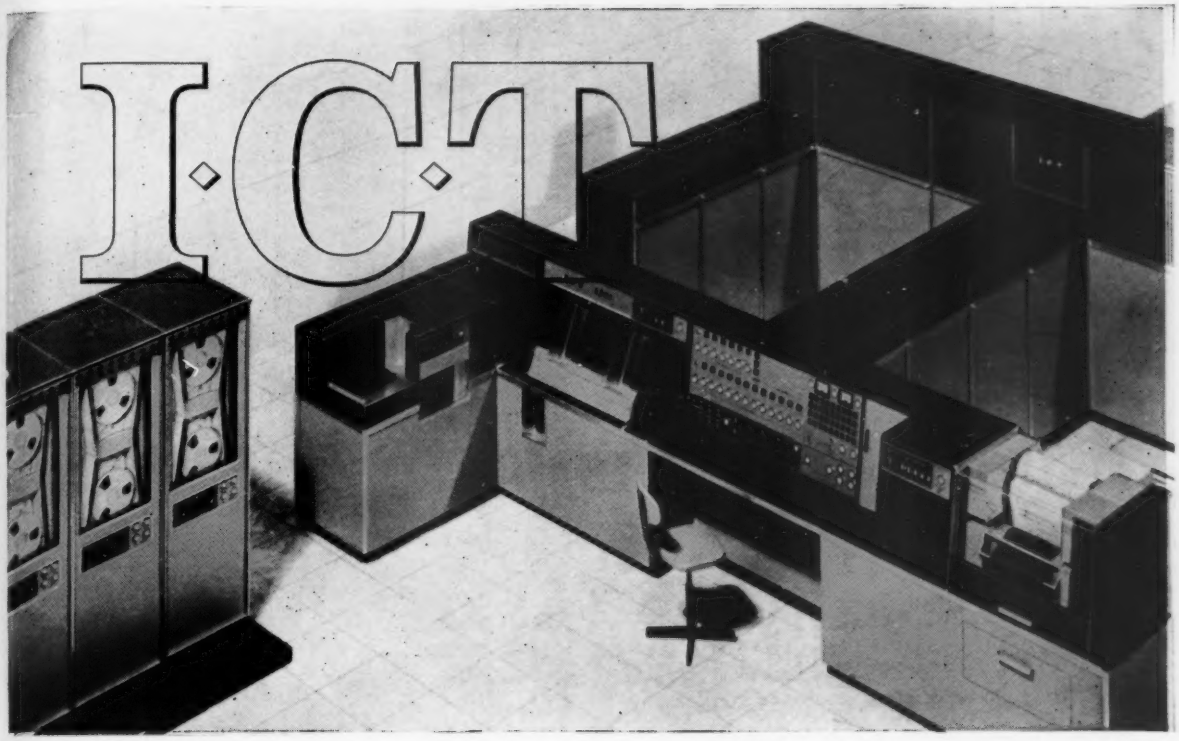

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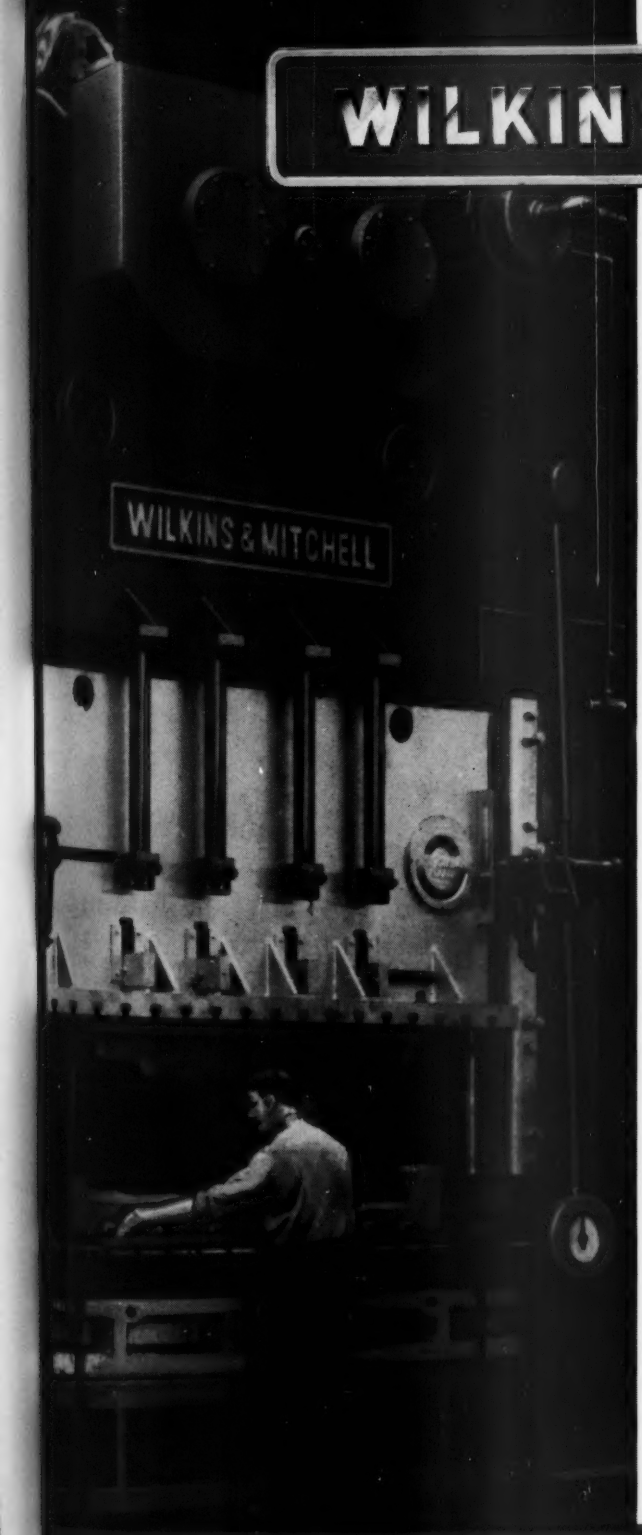

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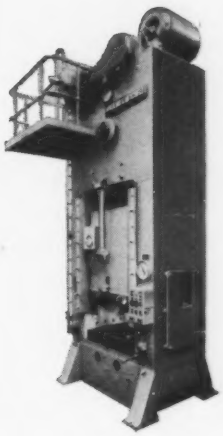

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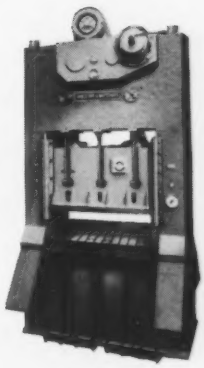

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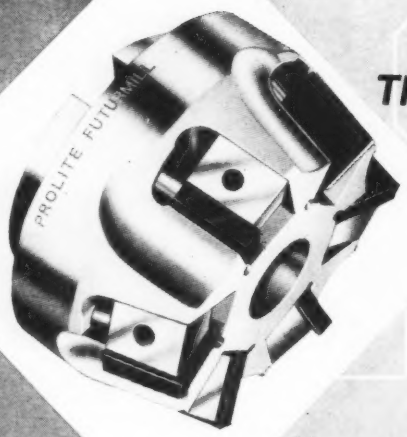

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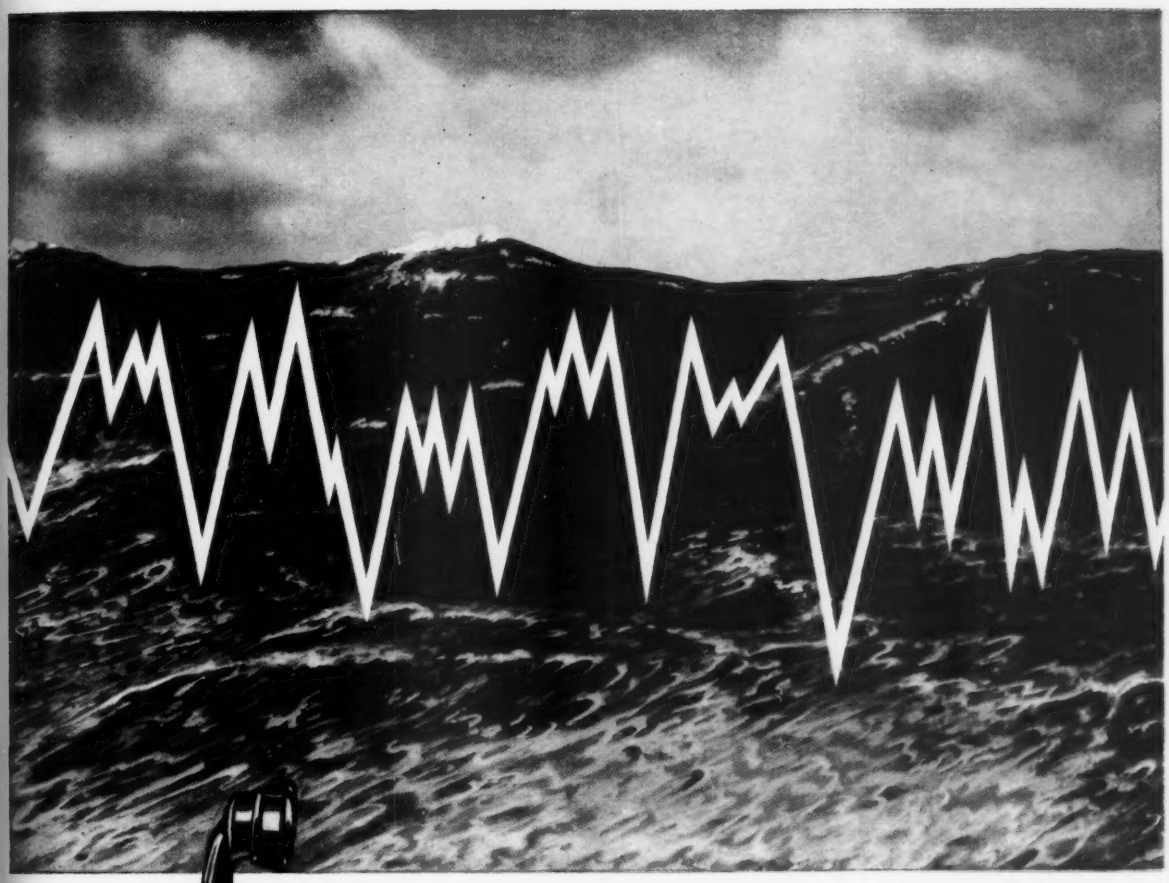

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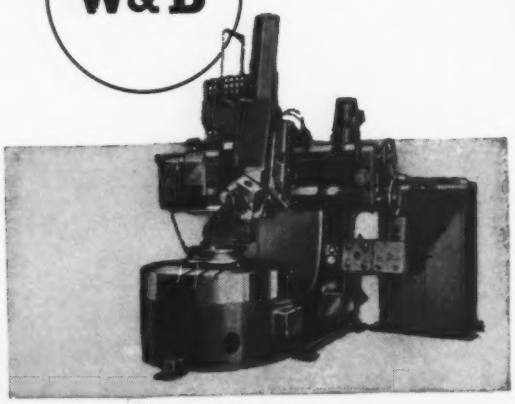

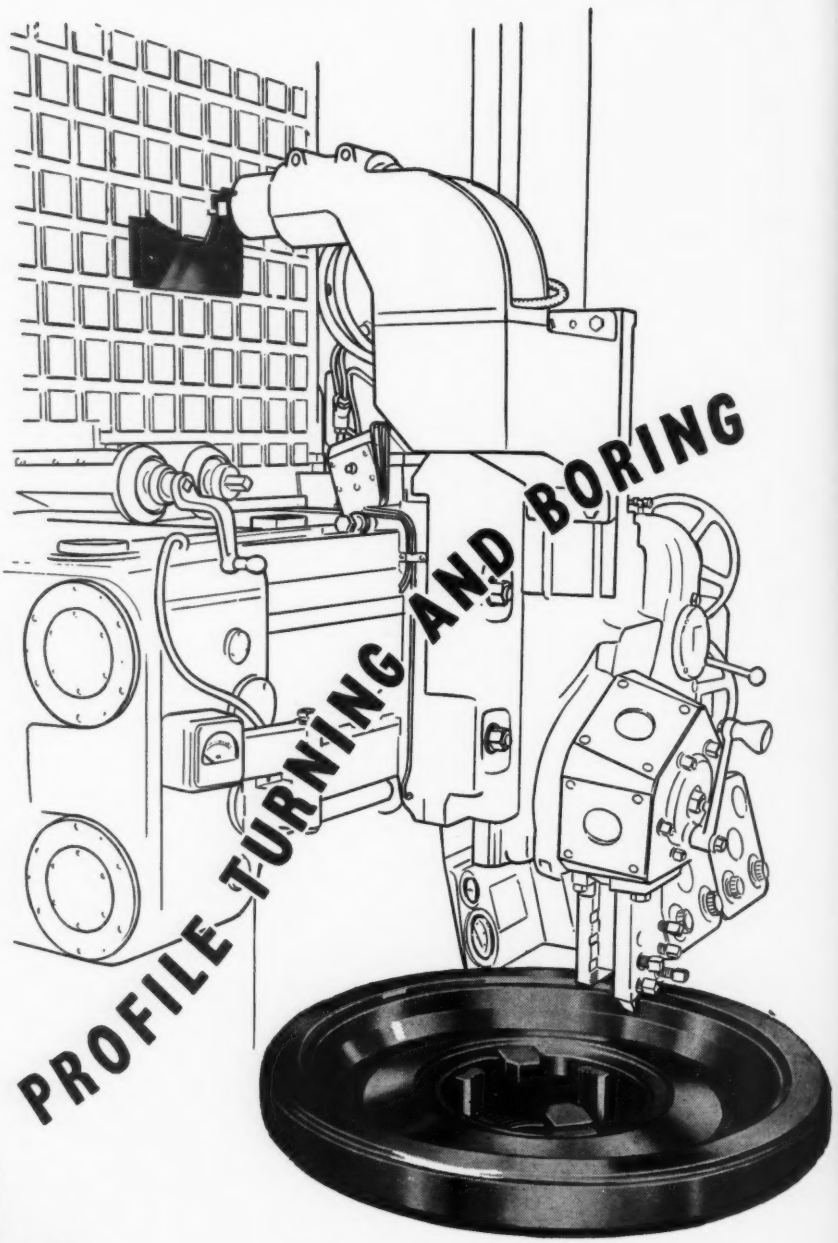

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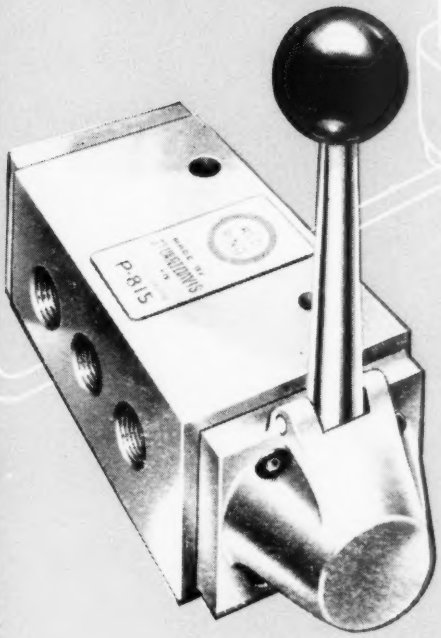

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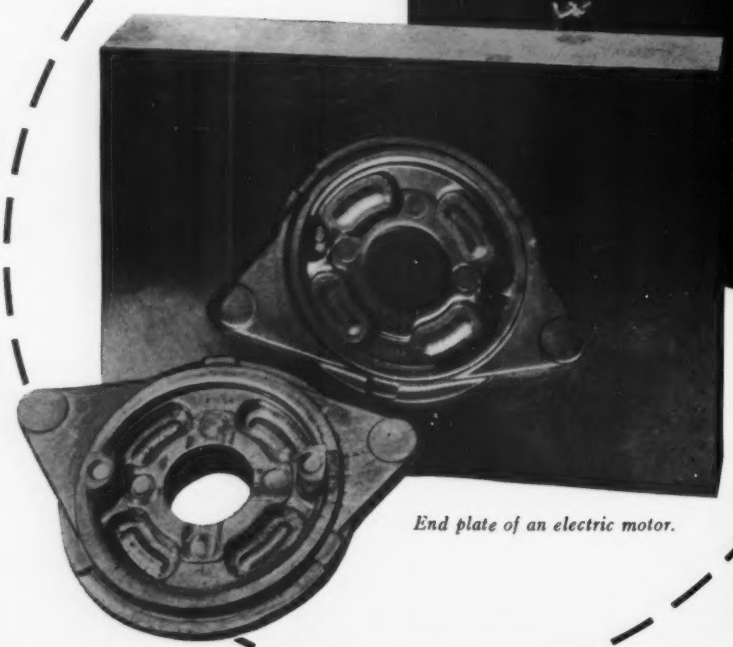

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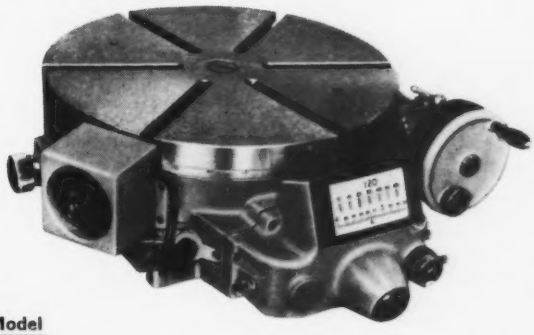

16 - inch Model

Platen diameter	16"
Scale reading	1 sec. of arc or 10 secs. of arc
Overall size	22" x 20½" x 5¾"

30 - inch Model

Platen diameter	30"
Scale reading	1 sec. of arc
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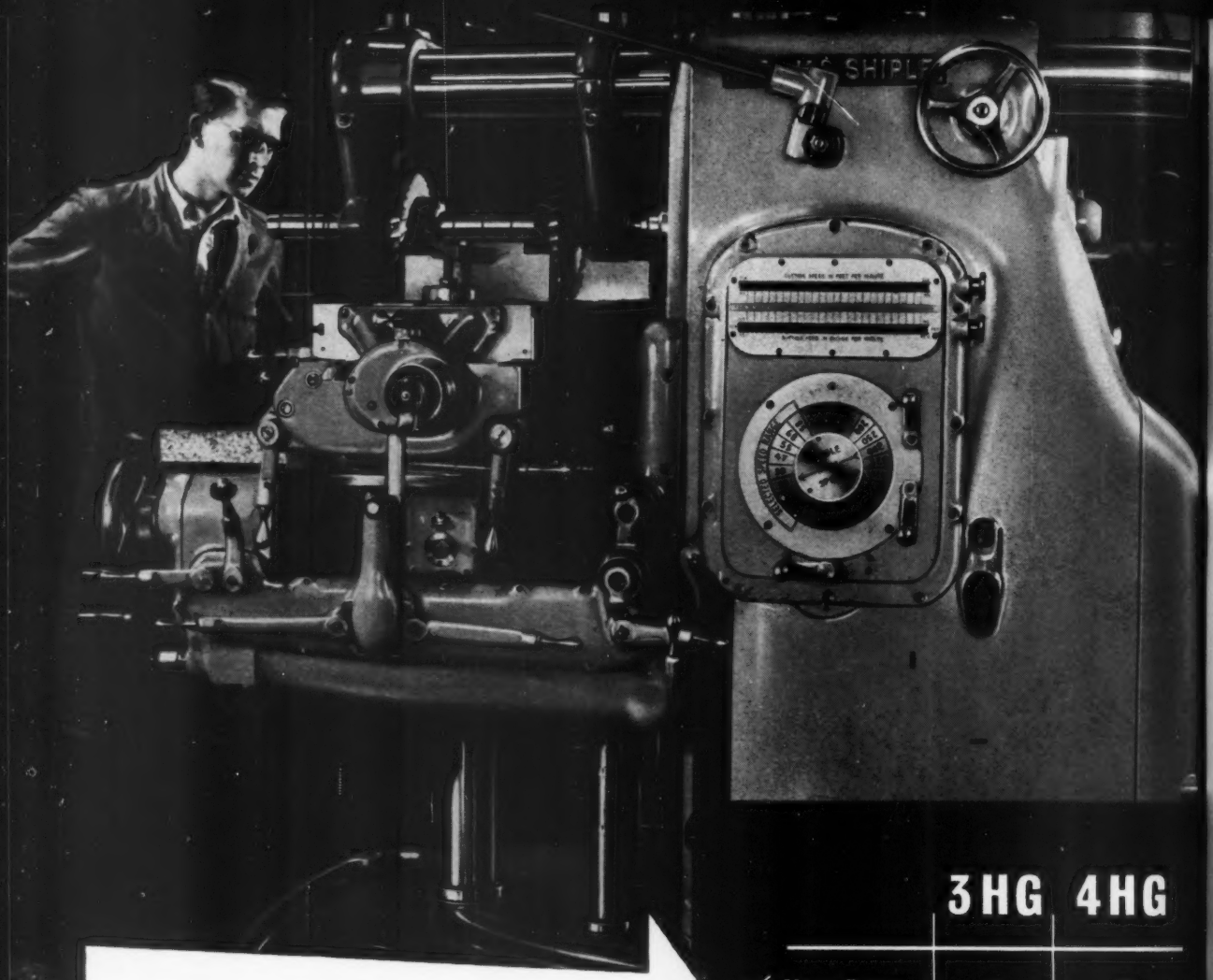

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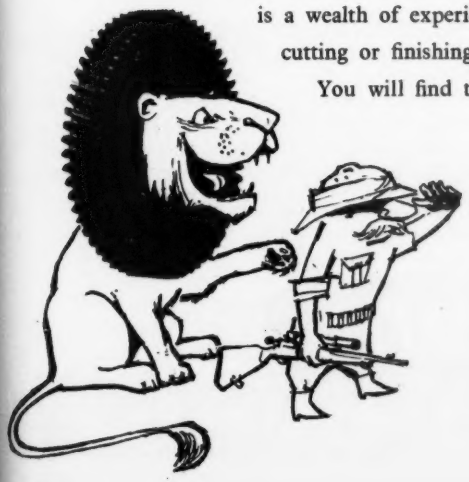


DAVID BROWN

100 YEARS 1860-1960

THE DAVID BROWN CORPORATION (SALES) LIMITED

TOOL DIVISION PARK WORKS HUDDERSFIELD
TELEPHONE HUDDERSFIELD 3500

DA/8937

RICHARD LLOYD

Engineers' SERVICE and SUPPLIES

SERVICE

A team of specialist engineers is now available to assist customers in the correct use and maintenance of our products. These engineers have considerable experience in one or other of the following types of operation :—

Milling ; Boring ; Reaming ; Tapping ;
Grinding and Scurfing ; Power Transmission.

In the event of any problems arising,a phone call or letter will bring a specialist engineer to assist on the spot.

SUPPLIES

Among the wide range of engineers' equipment manufactured and distributed by us are :—

"Galtona" Inserted Blade Milling Cutters, Boring Heads and Tool Holders, "Galtona" Ground Thread Taps ; Dies, Drills, Chucks, Solid Milling Cutters and Reamers, "Carborundum" and "Aloxite" Abrasive Products, Precision Tools, Electric Tools, Machine Tools and Small Tools, Power Transmission equipment—in fact "Everything for the Engineering Shop".

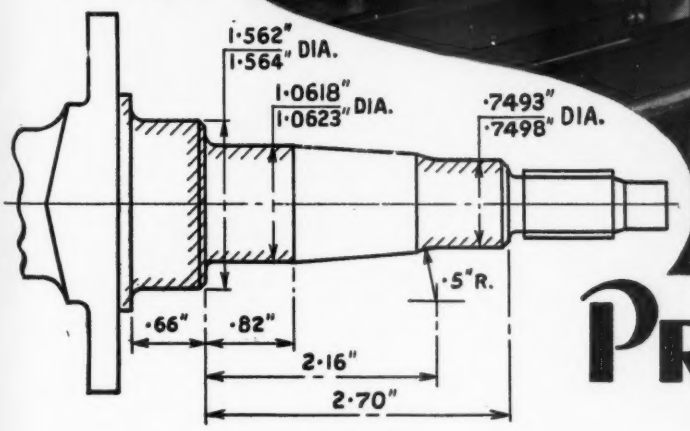
RICHARD LLOYD LIMITED

GALTON HOUSE, ELMFIELD AVENUE, TYBURN, BIRMINGHAM, 24

Telephone : Ashfield 1801, Telegrams "Cogs, Birmingham"

65 Seconds per Piece

Floor to Floor



GROUND WHERE MARKED //////
PART VIEW OF COMPONENT

PRECIMAX *Grinding*

Stub Axles at Armstrong Patents Ltd.

The key to this outstanding production achievement is plunge grinding on the PRECIMAX model MPB 12/24. The stub axle shown in the drawing is of 80-ton tensile steel and amongst the many PRECIMAX features contributing to ultra high speed performance is the accurate dressing of the wheel allowing the simultaneous grinding of three diameters.
PRECIMAX Grinding Machines are available in a wide range of types and sizes.
Our range includes precision fine boring machines as well as grinding machines. Send for full details.

LANDIS LUND LIMITED

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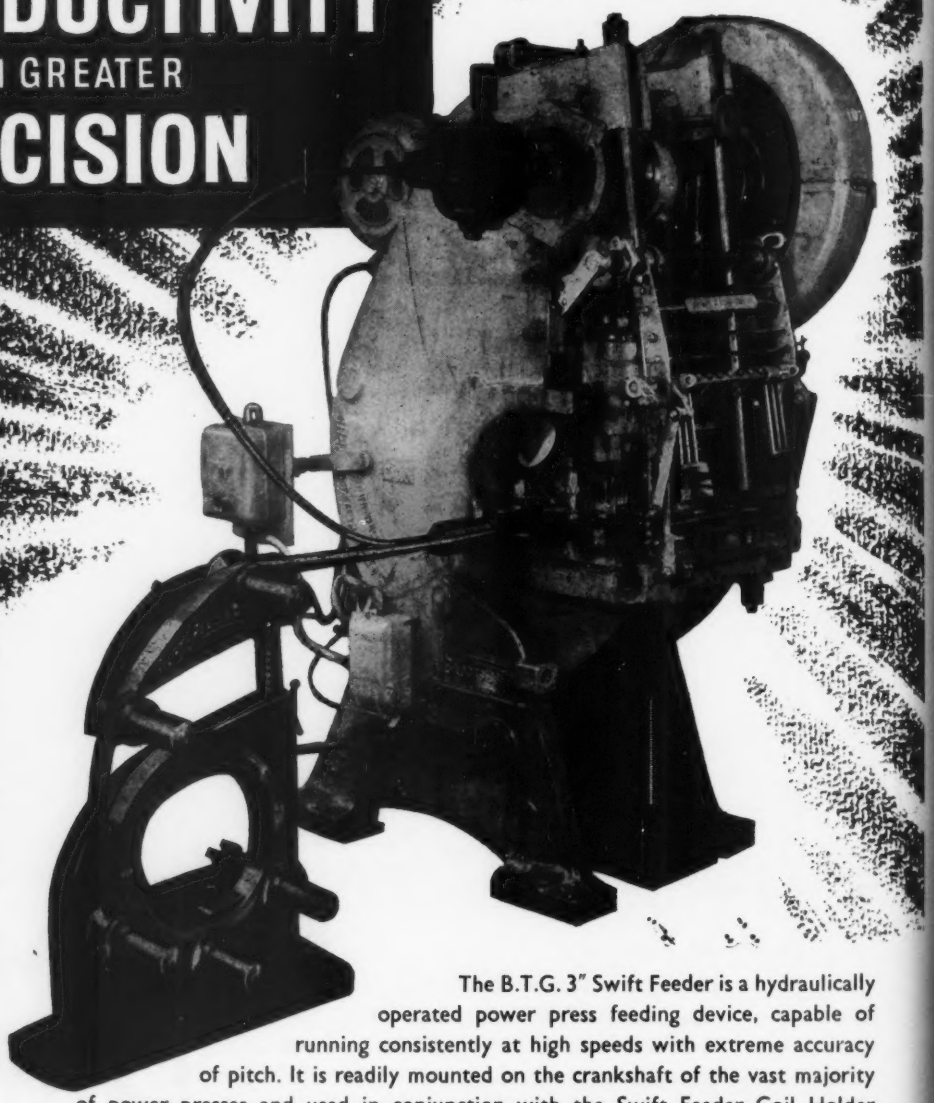
NRP/M2

INCREASED PRODUCTIVITY WITH GREATER PRECISION



BTG TRADE MARK

The B.T.G. 3" Swift Feeder is a hydraulically operated power press feeding device, capable of running consistently at high speeds with extreme accuracy of pitch. It is readily mounted on the crankshaft of the vast majority of power presses and used in conjunction with the Swift Feeder Coil Holder (which is adjustable for tool height and coil size) enables the press table to be kept clear of any obstruction.

The extreme simplicity of adjustment for pitch progression and material thickness makes the Swift Feeder ideally suited for both short and long production runs. Adjustment for width of material is rendered unnecessary by the open-sided gripper design.

THERE IS NO FASTER OR MORE CONSISTENTLY ACCURATE PRESS FEED THAN THE

SWIFT-FEEDER

Swift Feeders employed in production in our Associate Company may be seen at any time by appointment.

BIRMINGHAM TOOL & GAUGE CO. LTD., BIRMINGHAM 19
and 26 HOLBORN VIADUCT, LONDON, E.C.1.

A Member of the DENBRO Group

Mechanical tubing
does you a good turn...
Also consult us for..
... ducting
... storage tanks
... mild steel fabrications etc.
Markland Scowcroft
LTD.
COX GREEN WORKS, BROMLEY CROSS, Nr. BOLTON.
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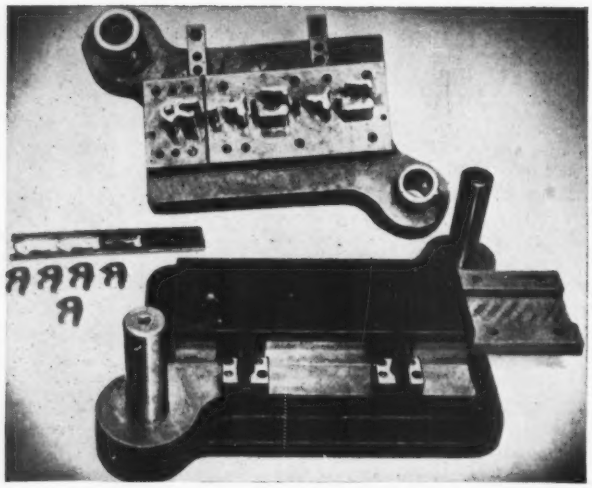
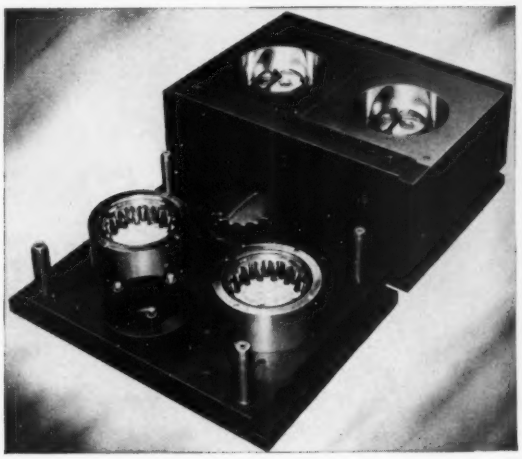
M 129

FOR SPECIALLY LONG RUNS



EDGAR ALLEN DOUBLE SIX SUPER DIE STEEL

Multi-stage tool for piercing, shaving and blanking levers, with double trigger stop feed. Output of 35,000 between grinds on steel .193 in. thick for Wilmot Breeden Ltd.



Compression mould in Double Six steel for making motor starter control knobs for Brook Motors Ltd.

Wherever the duty is severe, Double Six super die steel is recommended. The slightly higher cost is recovered many times over in the extra production life of the tool.

The cutting edge of the tool will last much longer than ordinary die steels because of the highly alloyed composition; it is non-shrinking, and suitable for intricate sections.

We have achieved some outstandingly long runs with this superior die steel. Please fill in the request form for more details of this and other special alloy steels.

EDGAR ALLEN & CO. LIMITED
IMPERIAL STEEL WORKS, SHEFFIELD 9

TS35/PE

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Please send data on "DOUBLE SIX SUPER DIE STEELS" to:

NAME .....

POSITION .....

FIRM .....

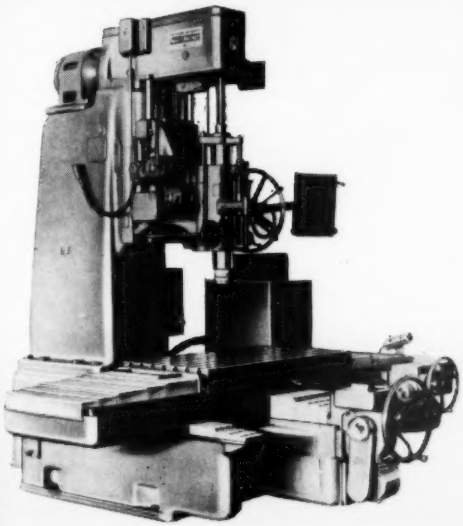
ADDRESS .....

.....

PRATT & WHITNEY

ONCE AGAIN SETS THE STANDARD

WITH NUMERICAL TAPE CONTROL



SIX-CHANNEL TAPE CONTROL APPLIED TO

PRATT & WHITNEY

No 3 E JIG BORER

In operation, the Planning Engineer first transfers to a Numerical Planning Chart all dimensional data required to determine the positions from blue-prints. Ordinary clerical help is then employed to punch this data into tape. The Operator now places the prepared tape into the machine's tape reader and establishes the zero point for the job. Once this is accomplished, he has only to push a button and the work is positioned for the first machining operation. Settings are made quickly, automatically and accurate to .0001 in.

Write for interesting details to the Sole Agents in British Isles for the Pratt & Whitney Co., of West Hartford, Connecticut, U.S.A.

BUCK & HICKMAN LTD.

OTTERSPOOL WAY, WATFORD BY-PASS, HERTS.

Head Office: P.O. Box 74, Whitechapel Road, London, E.1.

Branches: Alperton, Birmingham, Bristol, Glasgow, Leeds, Manchester.

CINCINNATI

1-18 PLAIN AUTOMATIC MILLING MACHINE

Full Automatic table cycles.
Automatic backlash eliminator to table.
Automatic spindle stop.
Dynapoise (vibration damping) overarm.

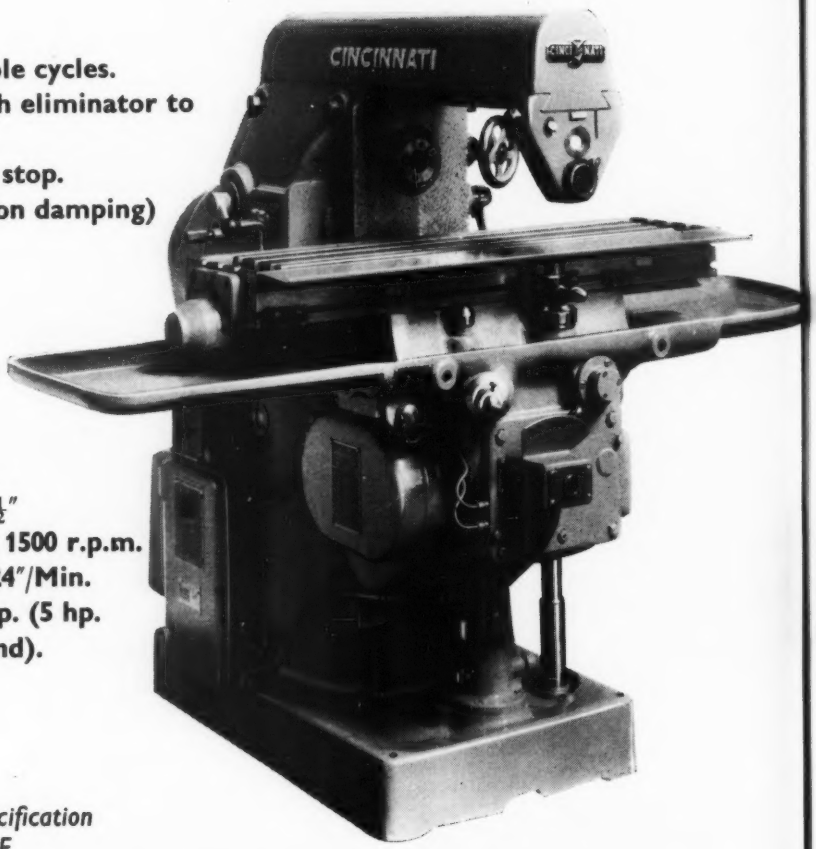


Table size 10″ × 35½″
Speed range — 50 - 1500 r.p.m.
Feed range — ½″ - 24″/Min.
Drive motor — 3 hp. (5 hp. available on demand).

Write now for full specification
Catalogue No. M-1555E

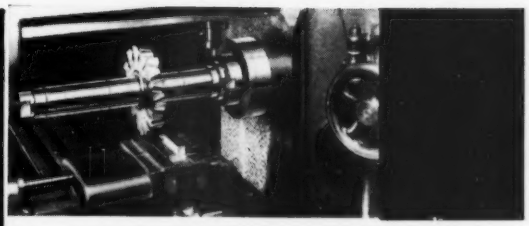
Agents: Chas. Churchill & Co. Ltd. — Birmingham, London, Manchester, Glasgow & Newcastle.

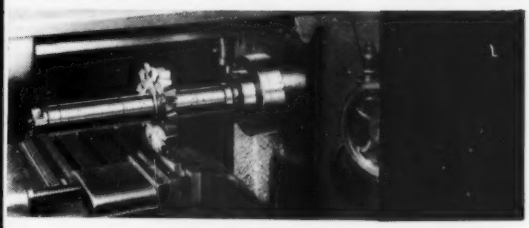
CINCINNATI MILLIN

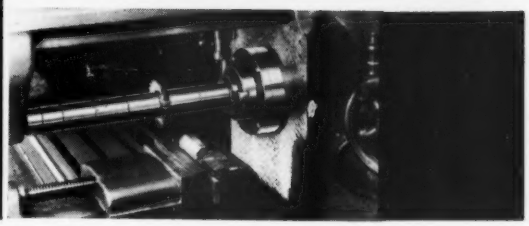
FOR BOTH SMALL AND LARGE QUANTITY PRODUCTION

24 off

—simple tooling using a standard machine vice for a typical short-run job in cold rolled mild steel in our own works.







Operation 1

Mill step.
Set-up ... 16 mins.
Milling
(24 pieces) 39 mins.
Total 55 mins.

Operation 2

Mill 5° angle.
Set-up ... 4 mins.
Milling
(24 pieces) 39 mins.
Total 43 mins.

Operation 3

Mill chamfer.
Set-up ... 9 mins.
Milling
(24 pieces) 27 mins.
Total 36 mins.

Continuous Production

—two automatic indexing fixtures with automatic clamping and unclamping.

Operation

Mill three slots in automobile transmission rings.
Production 300 per hour.

MACHINES LTD BIRMINGHAM 24

ARCHDALE

HYDRAULIC PRE-SELECT

for greater operating speed —faster penetrating capacity

Photograph by courtesy of
OTIS ELEVATOR CO. LTD.

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BLACKPOLE WORKS, WORCESTER · *Telephone: Worcester 27081 (6 lines)*

A member of the Staveley Coal & Iron Co. Ltd., Group

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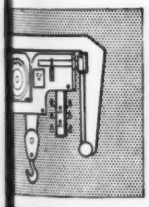
Manufactured under licence from Ferrand & Frantz Ing. Villeurbanne. British Patent No. 705, 148.

MODERN FACTORIES NEED

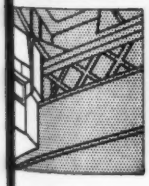
RÉEL ABOVE ALL ELSE

TO SAVE SPACE AND GIVE INCREASED HEIGHT OF LIFT

-with reduced building costs!



The underslung crab unit allows a highest hook position approaching close to the building height.



The driver's cage, glazed or open, is arranged to give maximum possible visibility in all directions.

Reel is the only modern overhead crane specially created to meet modern industrial demands for higher mobility and efficiency. The unique Reel design carries the crane to within inches of the roof, giving maximum height for lifting. Enclosed girder construction combines lightness with great strength, allowing more economical running and maintenance. There are capacities to suit all requirements. Handling of goods is faster, safer and more economical with Reel—
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THE BRITISH

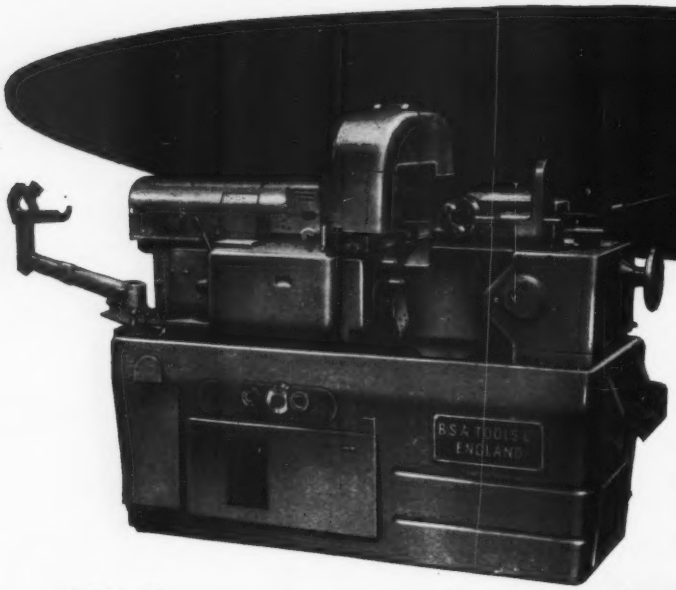
"RÉEL"

overhead travelling crane

BRITISH INDUSTRIAL

ENGINEERING COMPANY (STAFFS) LIMITED

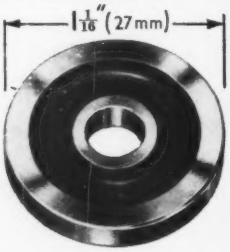
CORONATION WORKS · HAINGE ROAD · TIVIDALE · TIPTON · STAFFS · *Telephone:* TIPTON 1222/3/4



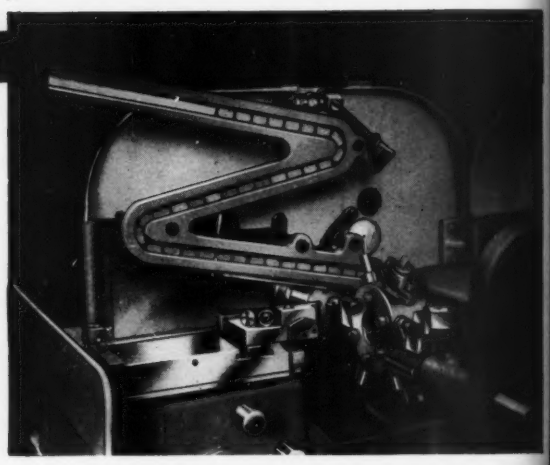
Many problems involved in the high-rate production of work of special nature or requirement are being solved by B.S.A. single spindle automatics. For work up to 2 in. diameter, from the commonplace to the most intricate, B.S.A. automatics maintain their reputation for speed with accuracy and reliability.

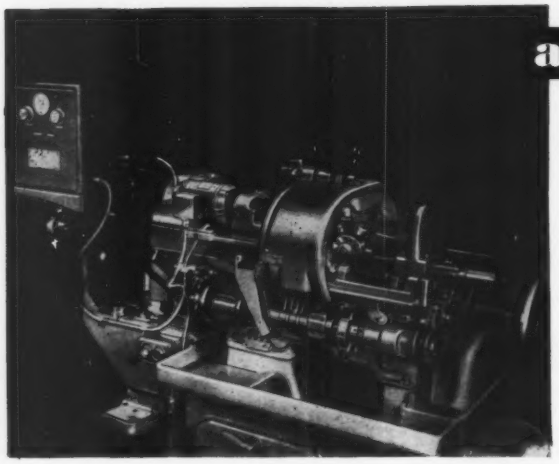
magazine loading

This bronze component is machined complete in 7 seconds on a B.S.A. 98 single spindle automatic. The "hairpin" magazine feeds the cast-blank to a loading block on the rear cross slide whence it is transferred to a chuck. Ten operations are performed involving tooling on the front cross slide, the turret and a stationary cutter within the workspindle, then the finished part is automatically released to fall in the pan.



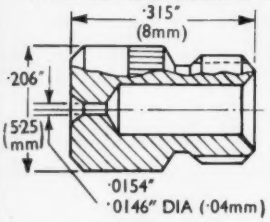
7 Secs





automatic inspection

Standard tooling on a B.S.A. 48 single spindle automatic produces this burner-jet in 3¼ seconds. Included in the sequence of operations is an electro-pneumatic means of automatic inspection of the fine hole. Any obstruction to an air-blast which is directed through the component causes a back pressure to be fed to a Sigma control unit. This operates a solenoid unit which stops the machine and lights an indicator. Drill replacement and removal of the defective component can then be made.



3¼ Secs

409

B.S.A. TOOLS LIMITED · BIRMINGHAM 33 · ENGLAND

Sole Agents in Great Britain:

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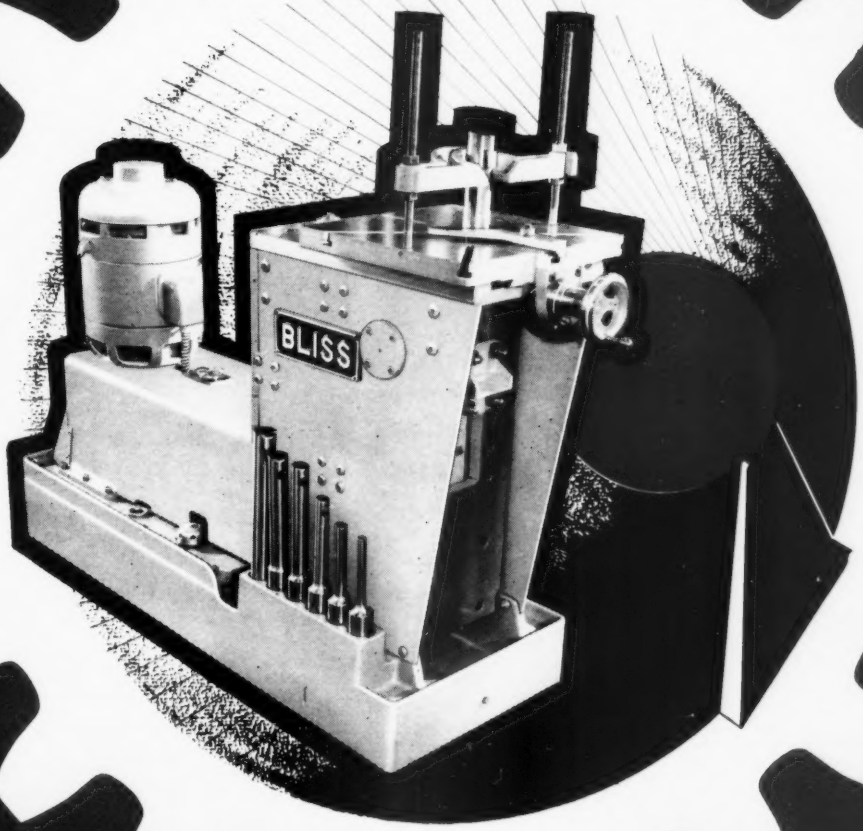
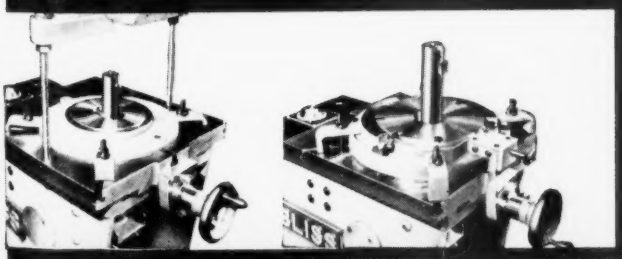
BLISS

HYDRAULIC KEYSEATER





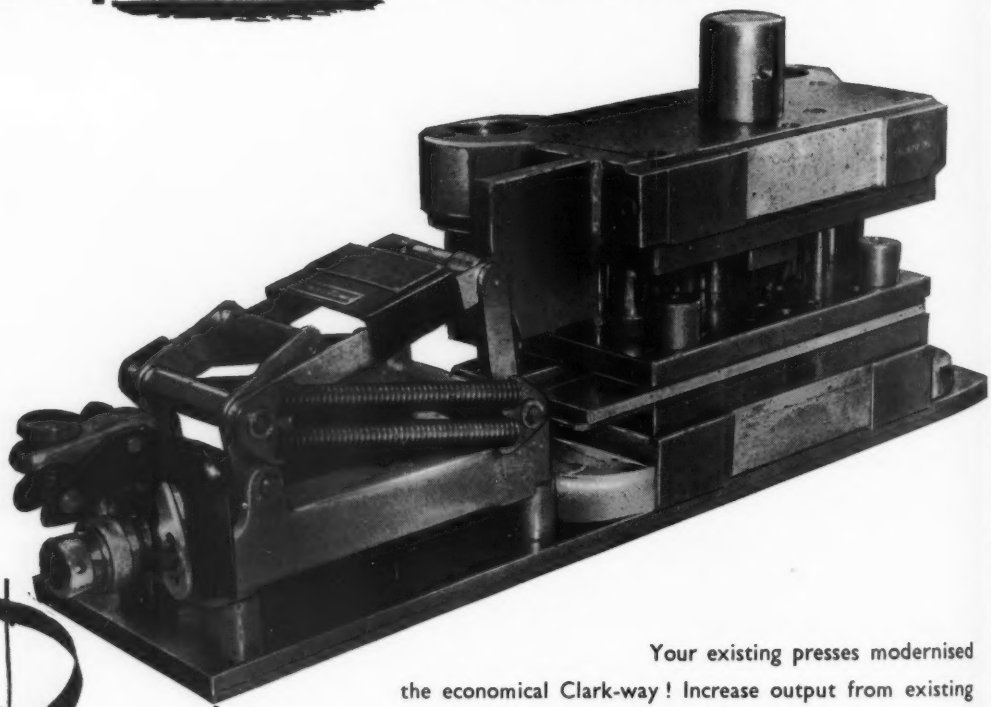
Accuracy with capacity rates, simplicity of operation and low maintenance are the characteristics of the new Bliss Hydraulic Keyseater. Other features are:

- Easy to set up
- Efficient for one piece or a hundred
- Wear resistant bushes
- Cast iron bronze bonded
- Unlimited workpiece size

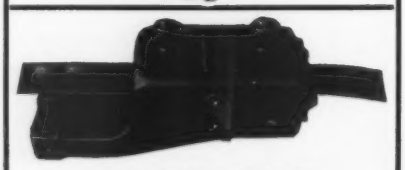
E. W. BLISS (ENGLAND) LTD.

for £25 -operators wage for a fortnight

you get a permanent automatic press



HORIZONTAL STOCK REEL



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PRESS SCRAP CHOPPER

Your existing presses modernised the economical Clark-way ! Increase output from existing staff, divert press operators to other work.

No complicated settings, no power costs, minimum set-up time, continuous operation, maximum accuracy, compact—and British in design and build.

✱ *Illustrated data mailed by return.*

a typical CLARK PRESS FEED running for three years has just completed 20,000,000 components!

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Clark's Press Equipment

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NRP 3314

Automatic sequence timing

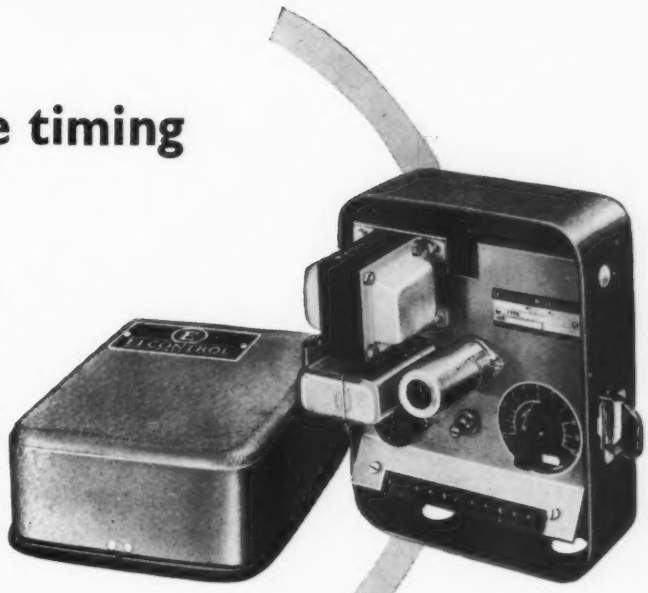
Elcontrol Timers for process and machine control include:-

PROCESS TIMERS
which start a process on closing the initiating switch, and stop it at the end of the time interval.

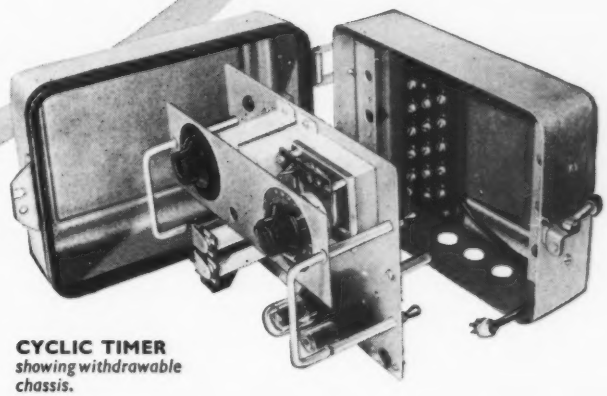
DELAY SWITCHES
which start or stop a process at the end of the time interval.

CYCLIC TIMERS
which automatically repeat a process at pre-determined intervals.

SEQUENCE TIMERS
which give full programming of complex processes embodying a number of timing stages.

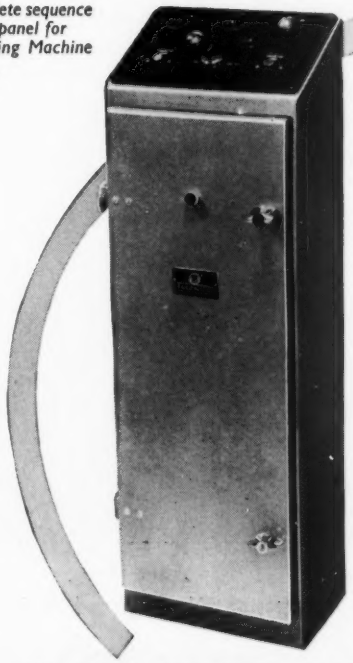


The new **TRU3 TIMER** *or Delay Switch £14.*



CYCLIC TIMER
showing withdrawable chassis.

A complete sequence control panel for Diecasting Machine control.



Repetitive accuracy of standard units is within ±2%, and a special high accuracy timer is available which betters ±0.1%.

Standard Timing Ranges cover between them 0.1 to 300 seconds.

Prices range from £14 upwards.

Elcontrol Timers are widely used on Resistance Welding Machines, Foundry Machines, Diecasting Machines, Filling Machines, Conveyors, Testing Equipment, Distillation Plant, Machine Tools and Process Plant throughout industry.

We shall be glad to advise on the use of Standard Timers or Special Control Systems for particular applications.

ELCONTROL *electronic control systems*

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NO FILTERS
NO PIPES
NO NOZZLES

In this new type of Water-Wash Spray Booth the exhaust air travels at very high velocity over the water surface entraining water. The air/water mixture, moving through controlled changes of direction, provides the scrubbing action.

★ **A NEW PATENTED PROCESS OF WATER TREATMENT... substantially increases the efficiency of these Booths.**

NO CLEANING OUT AFTER 1 YEAR'S CONTINUOUS DOUBLE-SHIFT WORK AT

Massey-Ferguson
(UNITED KINGDOM) LTD.

STRETFORD · MANCHESTER

This Booth was started up on production on 1st March, 1959, and has operated two nine-hour shifts on continuous painting of agricultural machinery. When last examined, there was an average depth of silt of 6 inches over the entire water tank bottom, an area of 290 sq. feet. A further 4 inches, making 10 inches in all, can be accommodated before cleaning is essential. After 1 year's operation, the fan and ducting were barely discoloured, the only maintenance cost being cleaning the floor inside the booth, routine greasing of bearings and similar preventive maintenance.

VISITS TO FACTORIES WHERE BULLOWS' NOPUMP SPRAY BOOTHS HAVE BEEN INSTALLED CAN BE ARRANGED ON REQUEST. WRITE TODAY FOR FULL DETAILS OF THIS OUTSTANDING BULLOWS' ACHIEVEMENT.

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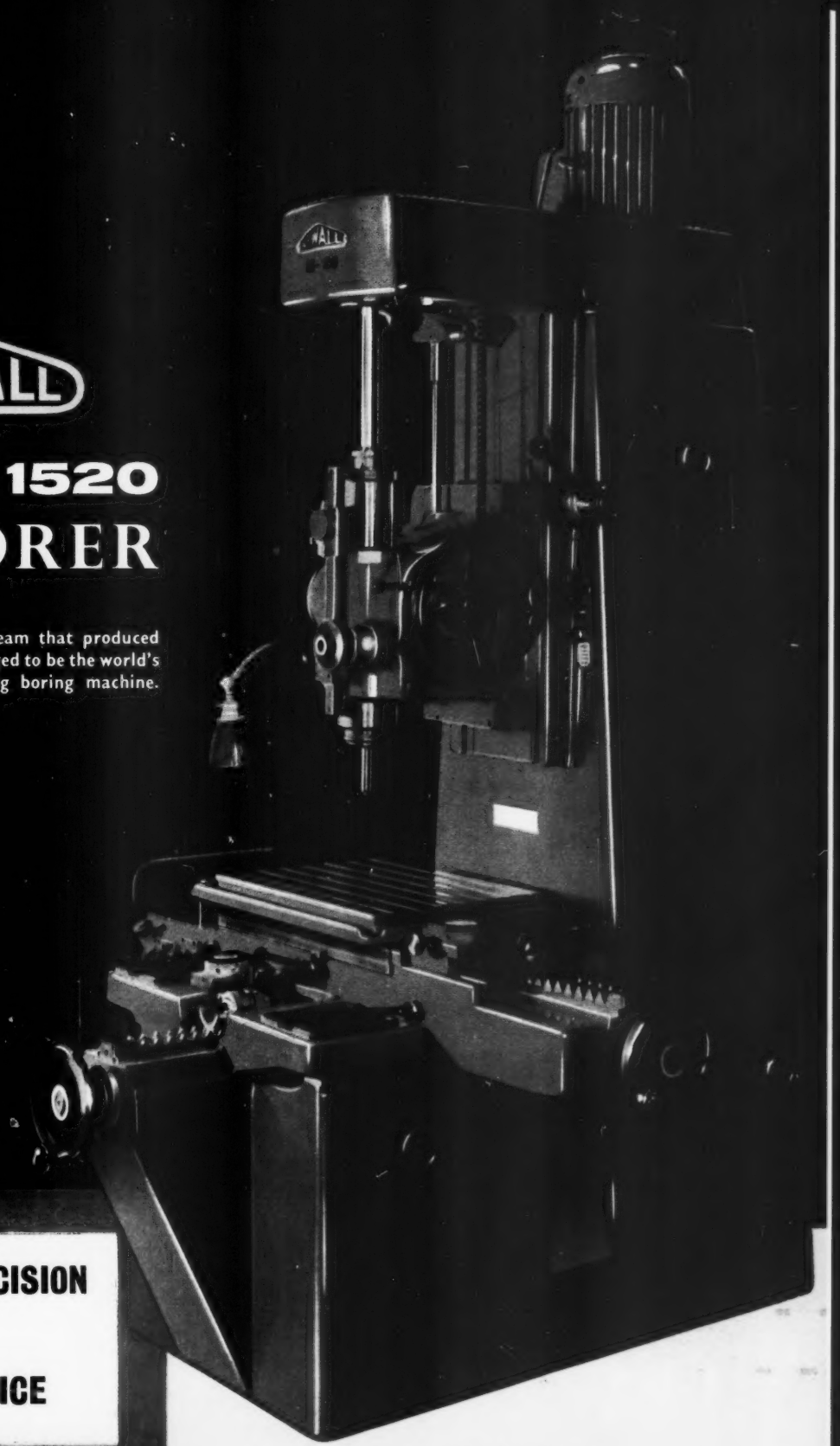
MODEL 1520
JIG BORER

Latest development of the team that produced the 'Spacematic'—acknowledged to be the world's fastest and most accurate jig boring machine.



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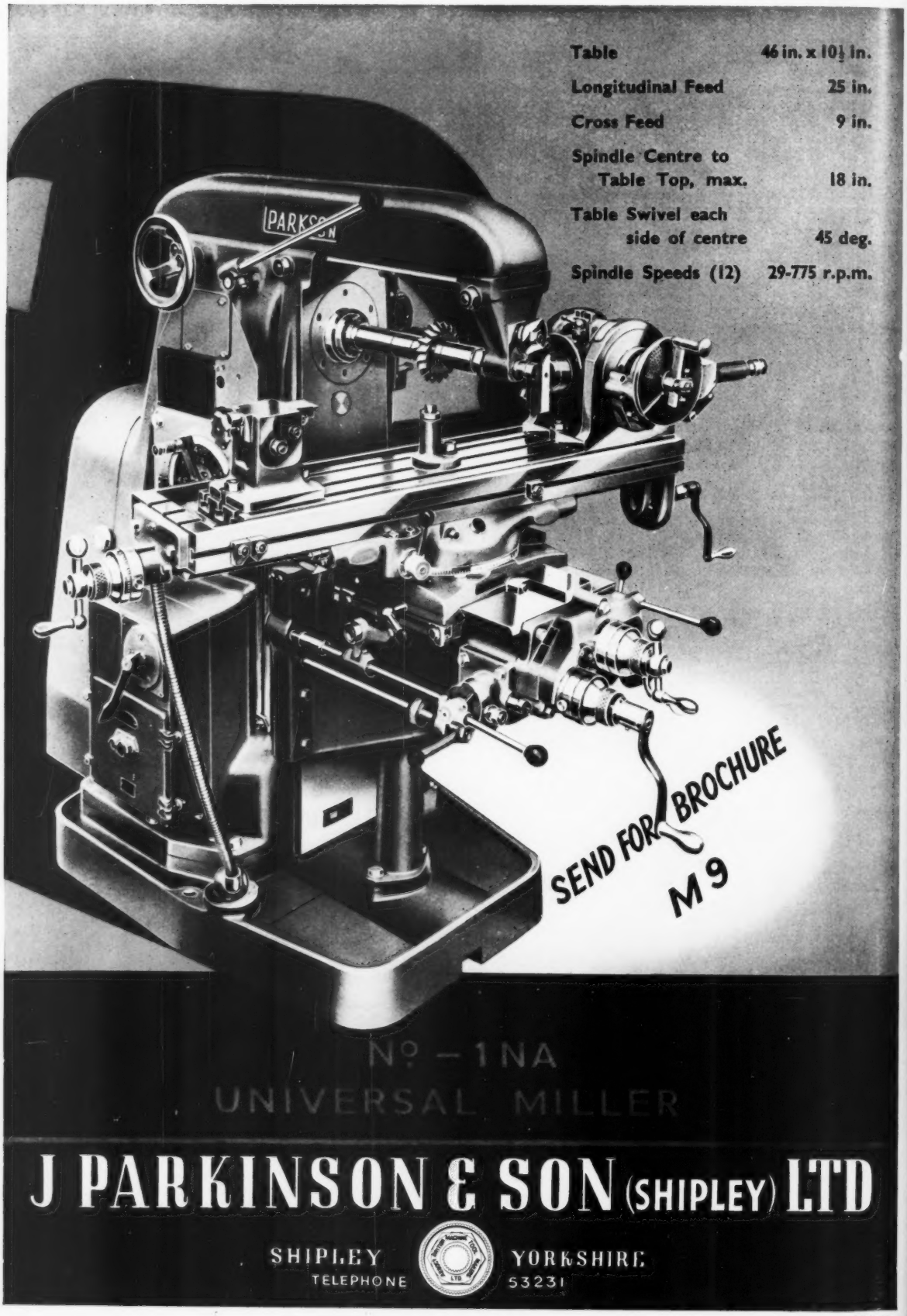
Table 46 in. x 10½ in.
Longitudinal Feed 25 in.
Cross Feed 9 in.
Spindle Centre to Table Top, max. 18 in.
Table Swivel each side of centre 45 deg.
Spindle Speeds (12) 29-775 r.p.m.
SEND FOR BROCHURE M 9
No. – 1NA
UNIVERSAL MILLER
J PARKINSON & SON (SHIPLEY) LTD
SHIPLEY YORKSHIRE
TELEPHONE 53231

P367-1B

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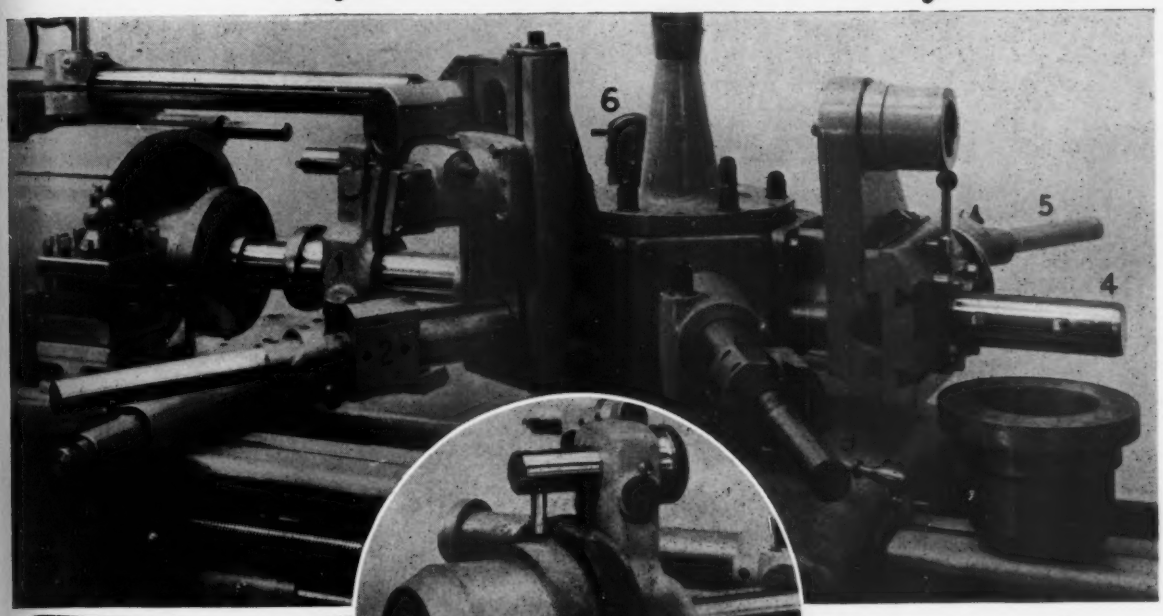
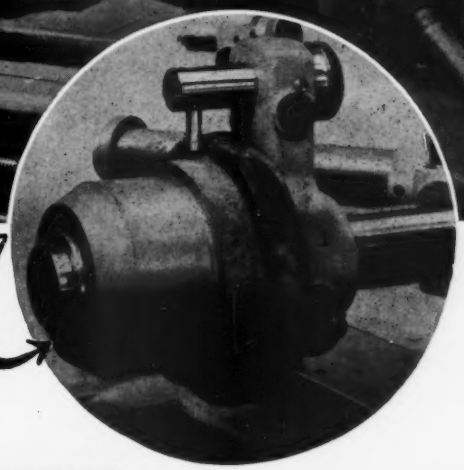
3.	Roug Roug
4.	Und Tool
5.	Micr Finis Finis
6.	Rem load

Maximum Production Special Tool Layouts





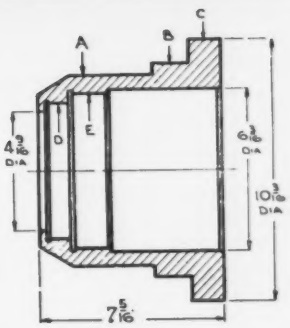
PULLEY SLEEVE

Ward

No. 8 TURRET LATHE

FITTED WITH 15in TUDOR 3-JAW CHUCK

DESCRIPTION OF OPERATION	Tool Position		Spindle Speed R.P.M.	Surface Speed Ft. per Min.	Feed Cuts per inch
	Hex. Turret	Cross-slide			
1. Chuck on A (using Loading Attachment)	1	—	—	—	—
2. Rough Face and Rough Turn C (1st cut)	—	Front 1	85	235	48
Rough Bore $6\frac{3}{16}$ and $4\frac{9}{16}$ and Rough Turn C	2	—	85	230	70
3. Rough Bore D and E	3	—	85	133	70
Rough Turn B and Face Back of Flange	—	Front 2	85	225	70
4. Undercut and Chamfer Bores (Recessing Toolholder)	4	—	85	133	Hand
5. Microbore D, E and $6\frac{3}{16}$ dias.	5	—	175	285	98
Finish Turn C	—	Front 3	175	465	70
Finish Double Face Flange	—	Front 4	175	465	70
6. Remove Part from Chuck (using Unloading Attachment)	6	—	—	—	—



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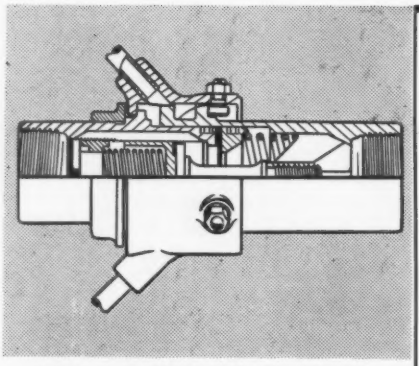
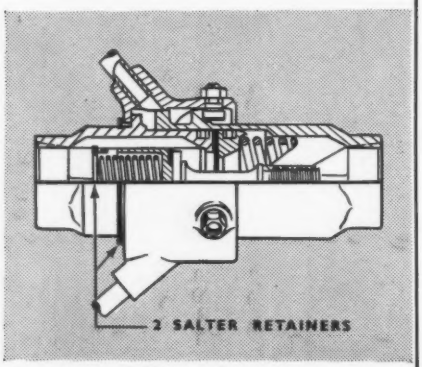


THE OLD WAY Self-sealing coupling used over-sized internal and external threaded retainers... costly milling, turning and threading operations were necessary, and assembly slow and difficult.



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inner retainer (20 mins)	5/4¼
threading (4 mins)	1/0½
ASSEMBLY	6¼
total labour saving	10/11
MATERIAL	
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TOTAL SAVING WITH SALTER RETAINERS	14/4

* **14/4 saved on each unit by use of 2 SALTER RETAINERS**

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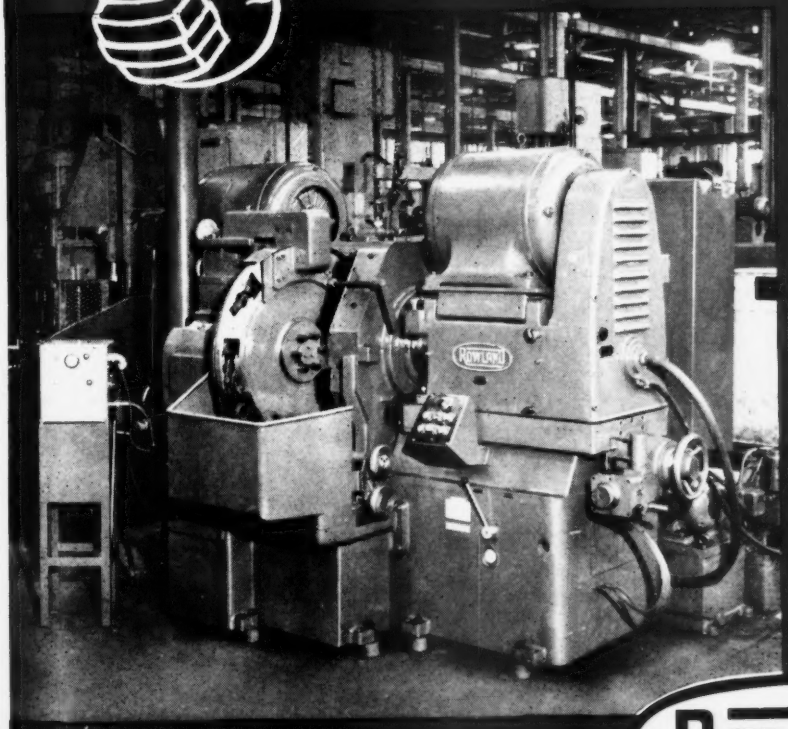

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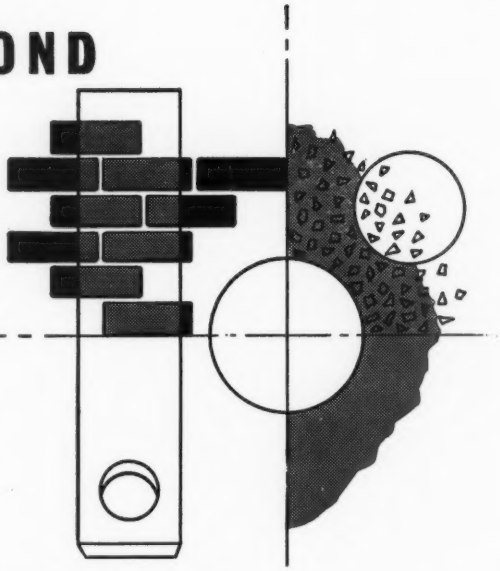

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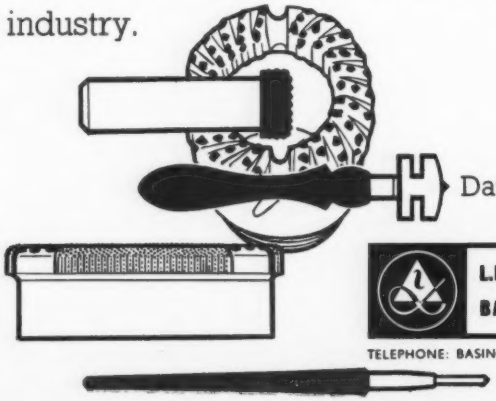

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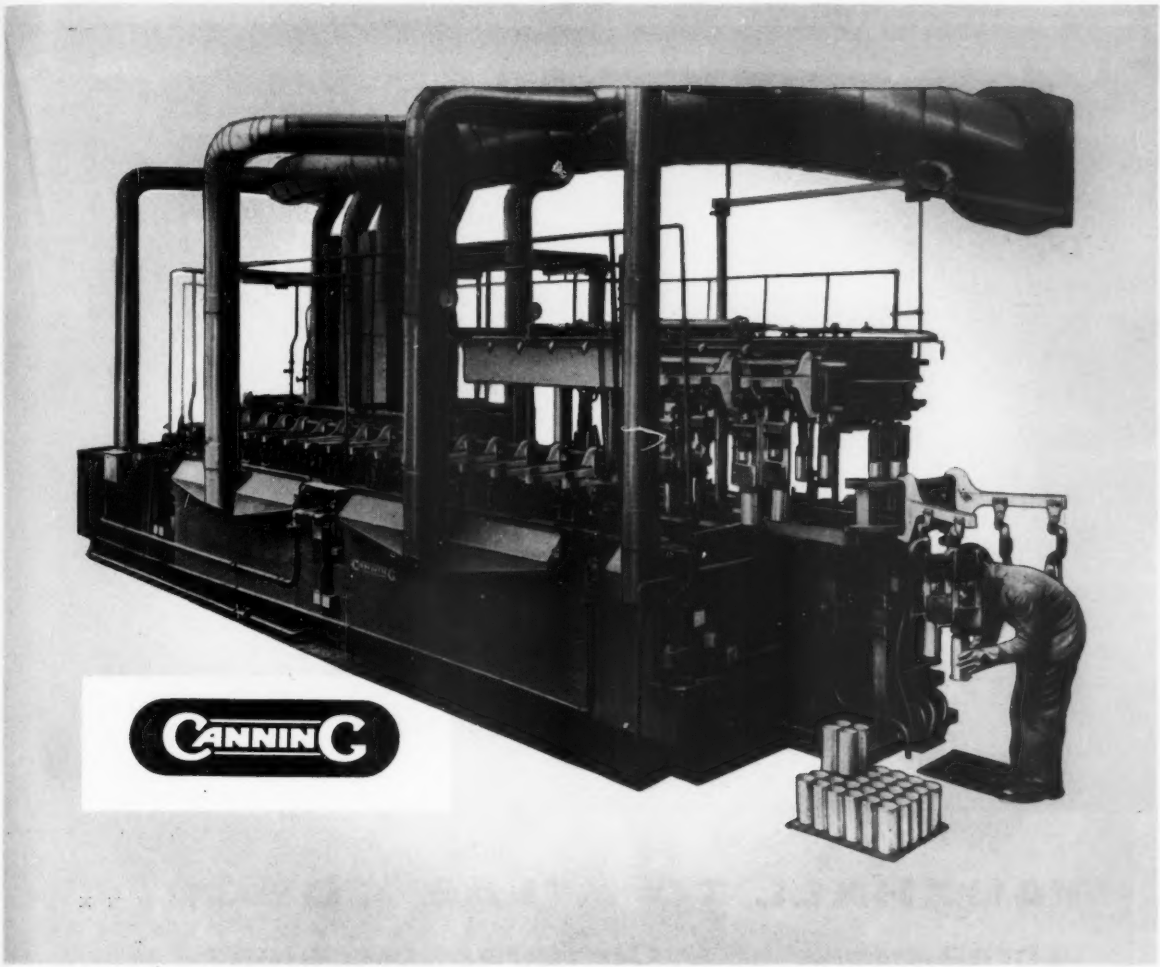

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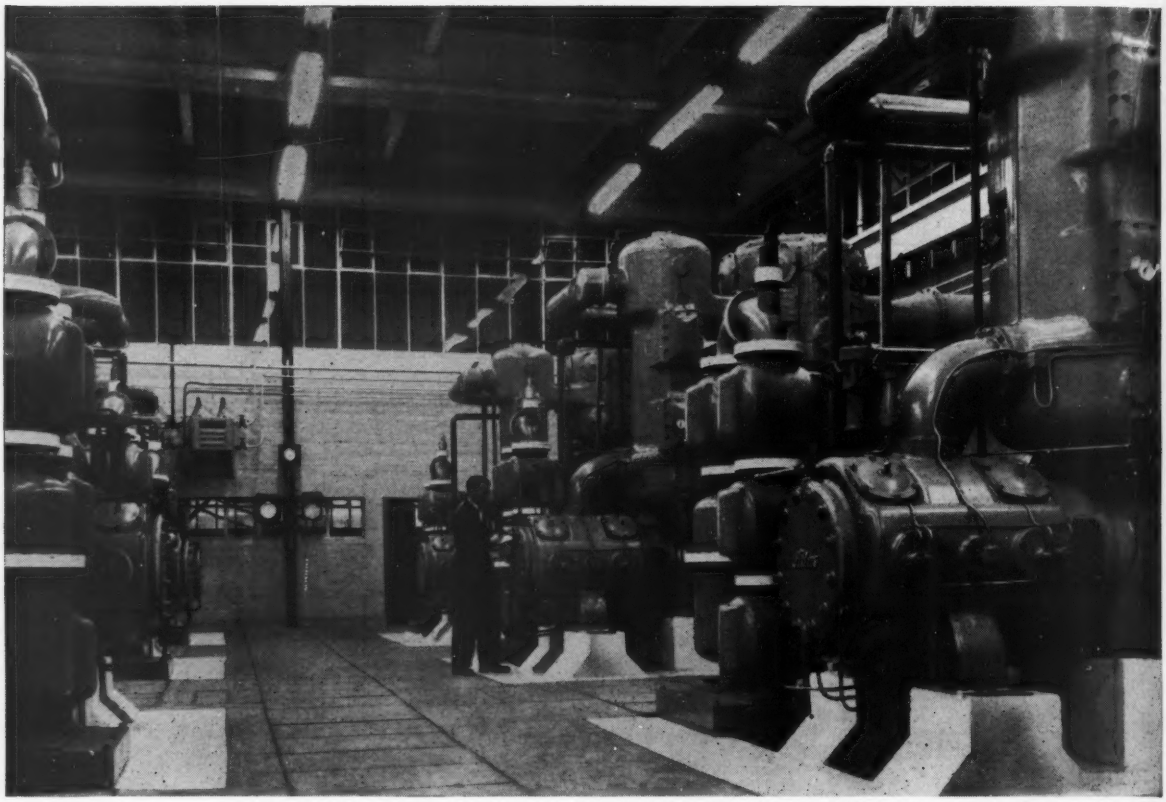

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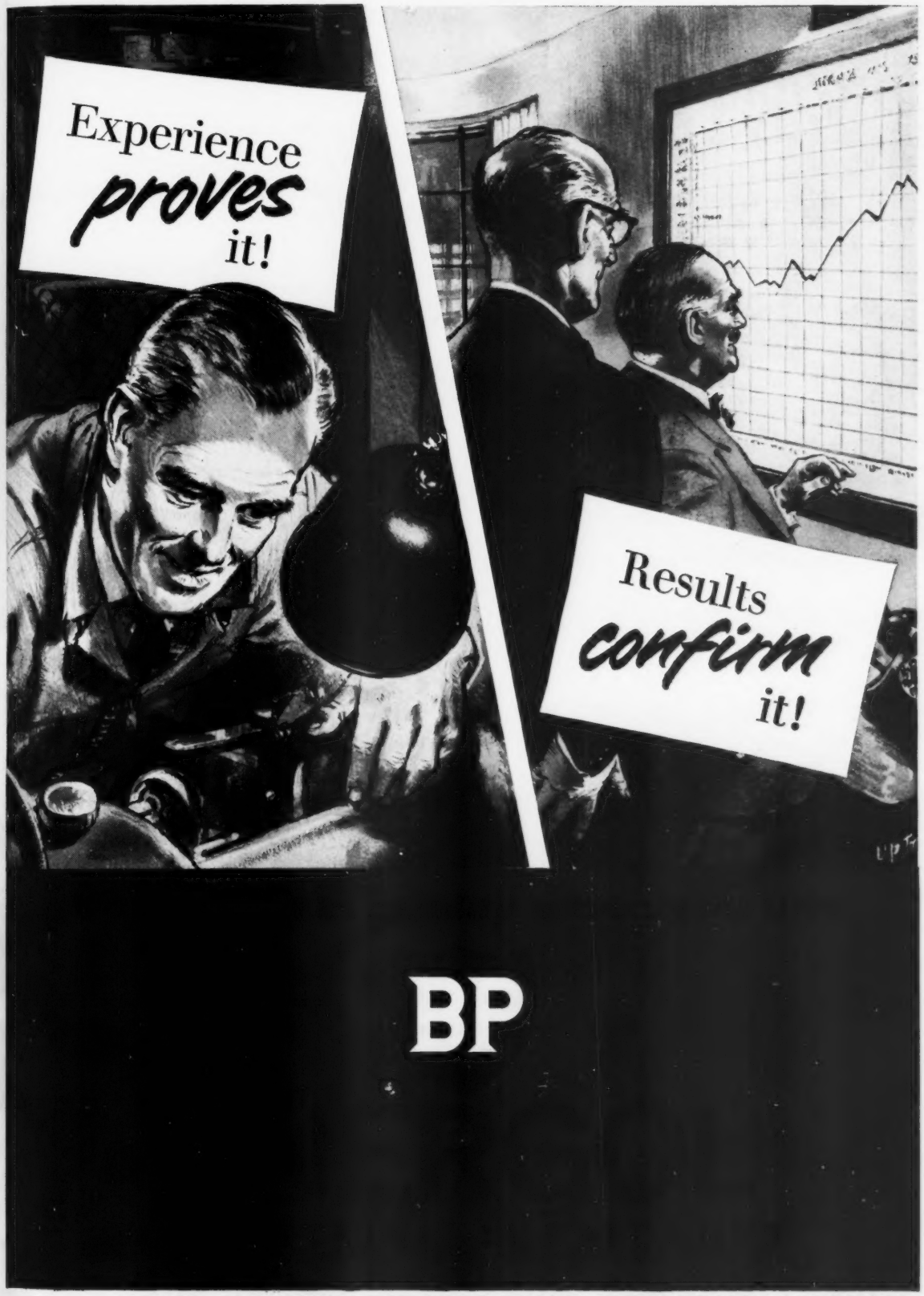

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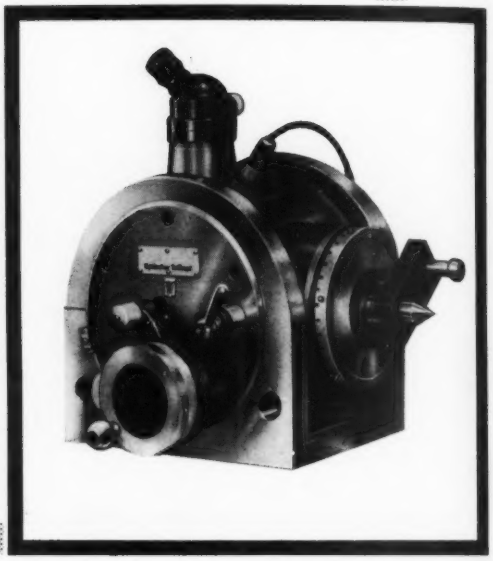

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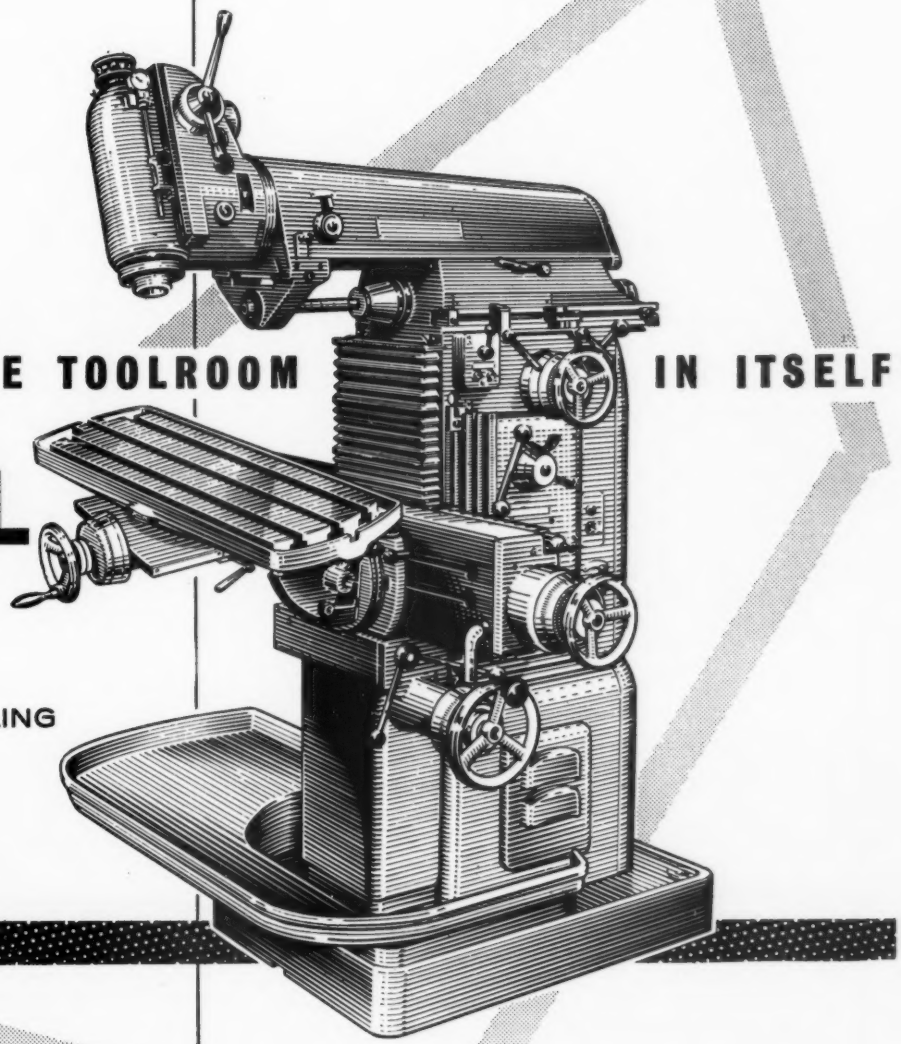

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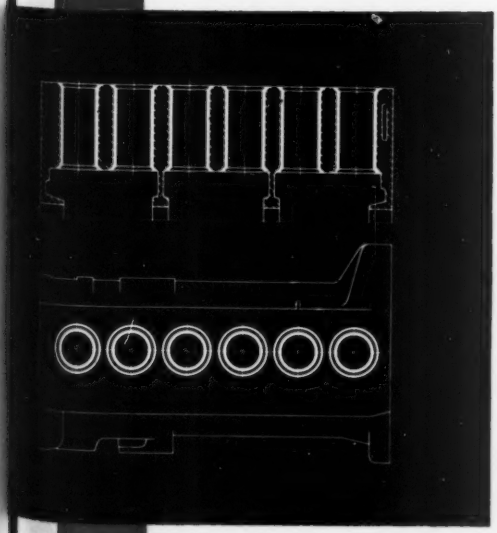

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Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, Shell Dromus Oils have been reformulated and these new cutting oils now produce bland emulsions, which considerably reduce the risk of skin trouble to operators.

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The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the welcome position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

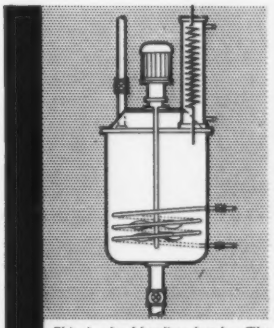
The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

This field testing and final development proceeded for two years whilst production plants were erected at points so chosen as to give the most economical and rapid delivery throughout the United Kingdom.



This is the blending kettle. The reflux condenser beside the stirrer motor prevents the loss of constituents volatile at the blending temperature.

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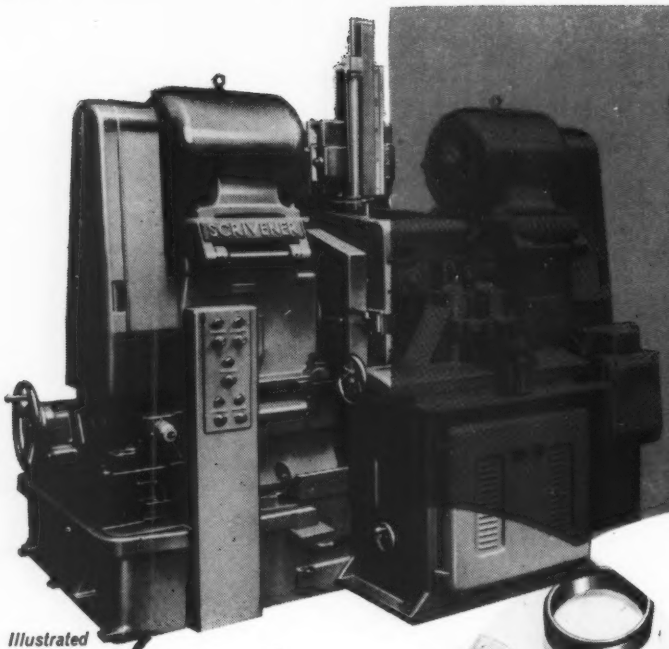
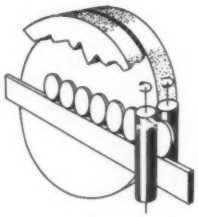


Illustrated Scrivener 24/30



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Oscillating Feed

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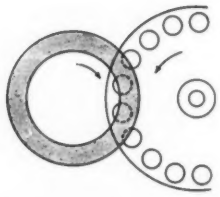

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The Production Engineer

THE JOURNAL OF THE INSTITUTION OF PRODUCTION ENGINEERS

VOL. 39 No. 11 NOVEMBER, 1960

LEAST COST SCHEDULING OF DAILY LOCAL DELIVERIES

an application of dynamic programming

by Professor Ronald W. SHEPHARD

Industrial Engineering Department,

University of California

This Case Study was prepared by Professor Shephard from research undertaken by him with a graduate student in his Department.

It formed part of the Seminar on Operational Research held at The Institution of Production Engineers Headquarters in April, 1960.

INTRODUCTION

THE problem analysed in the following case study is one of daily scheduling of deliveries between public carrier and private company fleet. This kind of decision making, which frequently arises, is ordinarily done on an intuitive basis by rather unsophisticated methods. It is possible, however, to schedule deliveries in a routine way so as to guarantee a close performance to an ideal of minimum costs for transportation.

A precise mathematical justification for this routine is given in the following pages. The argument is made by introducing a serial ordering of the deliveries to be made during a day, in terms of certain cost coefficients, and showing recursively that the scheduling rule proposed is near optimum. The recursive demonstration consists in successively analysing the costs involved for first one delivery, then two deliveries, and so on, up to an arbitrary number of deliveries which may have to be made.

A simple near optimum scheduling rule is sought rather than one defined by an involved mathematical calculation, because the scheduling has to be done on a daily basis. Moreover, for retrospective evaluation of optimum fleet size it is neither convenient nor practical to make involved daily scheduling for comparative cost calculation.

THE scheduling, between common carrier and private fleet truck, of local delivery of product from manufacturer to customer is a daily decision problem of some complexity, because the assignment variables are discreet and ordinarily many in number. For any given size of private truck fleet, the most efficient assignment of deliveries (in the sense of least total delivery costs) is not necessarily one in which a private fleet is used to capacity each day, and the deliveries to be scheduled each day may be highly variable in number and kind.

This scheduling problem has been studied in detail for a manufacturer of glass containers, and is now reported.

By use of recursion methods (dynamic programming) and explicit consideration of the special properties of the cost function involved, a simple decision rule is found for scheduling deliveries which is approximately optimum, and an expression is given for a bound upon the deviation from exact minimum cost thereby entailed. The bound is evidently small and an exact minimum cost scheduling is neither desirable nor required, particularly in view of the practical limitations of getting precise cost data and the difficulties of making daily an exact calculation of optimum scheduling.

Having determined an approximately optimum daily scheduling decision rule, the question of optimum private truck fleet size naturally arises. Comparative cost calculations may be made for various hypothetical private fleet sizes related to the deliveries encountered during an immediately previous year, using the near optimum daily scheduling rule as a basis for determining minimum operating costs connected with each fleet size, and private trucks may be retired or purchased annually to control the private fleet at near optimum size. The planning period suggested, i.e., one year, may be increased or decreased, depending upon the market circumstances and practices used for making and underwriting capital investments. The control thus obtained will be comparatively close to a minimum for delivery costs, provided the seasonal variation of average daily number and character of deliveries do not fluctuate violently from one planning period (e.g., year) to the next. If the annual variation is great, the problem of optimizing fleet size may be complex indeed, because forecasts of the seasonal variation of average daily volume alone are not sufficient. Changes in the character (i.e., destination and related volume of goods) of deliveries may have to be forecast.

Regardless of how well an optimum fleet size can be determined, it is important to have an approximately optimum daily decision rule for assignment of deliveries between private truck and common carrier. The operating decision to be made arises day by day, no matter how well the decision for investment in company trucks has been made, and considerable funds may be at stake, particularly in the case study presented here, where delivery costs are a substantial part of total costs. The largest savings may be derived, in some instances, from correctly assessing the optimum size of private truck fleet.

1. the actual case studied

The manufacturer produces glass containers such as milk bottles, canning jars, beer bottles, wine bottles, and soft drink bottles.

The product is low density, high bulk and usually delivered in truckload lots, or multiples of the same.

Customer orders are demands for receipt of goods on a particular day, requiring delivery sometime during that day. Since the demands for deliveries have pronounced seasonal, as well as daily variation, it is impractical to have a private truck fleet of sufficient size to serve all possible daily deliveries. Hence, each day, deliveries have to be scheduled between company trucks and common carrier.

The area served is such that no delivery requires more than one shift (i.e., 8 hours) delivery time, and, since orders for delivery are demands for receipt on a particular day, the scheduling problem is one of daily local deliveries.

Less than truckload orders are rare and may be easily combined into single deliveries at adjacent destinations. In other circumstances, where orders are predominantly less than truckload lots, the combination of orders into deliveries for assignment to a particular truck raises a travelling salesman-like problem which requires special study not undertaken here. Then the scheduling problem requires assignment of orders into single deliveries as well as scheduling of such deliveries between private truck and common carrier.

For the case at hand, no distinction is made between the drivers and the various hauling units of the private fleet because wages of drivers, characteristics of trucks and operating costs are essentially homogeneous. Hence the matching of a particular fleet unit and driver to a particular delivery is not important.

No restriction is placed upon the availability of common carrier, because ample services of the same are readily obtainable, barring strikes of truck drivers.

The company drivers are paid wages on an incentive basis as follows: each driver receives a common guaranteed daily base pay, whether he drives a truck or not during the day, and there is one driver for each company truck. These guaranteed base wages of drivers are regarded as fixed costs for the operation of the company fleet. In addition to the base pay, each driver receives an incentive pay for the deliveries he makes, computed as the product of the hourly incentive rate (common to all drivers) and the standard time for the delivery determined realistically as the time required to make the round trip from manufacturer to customer. The drivers adhere rather well to the standard delivery times in order to get the largest daily wage. This incentive system serves to provide Management with a means of regularizing the performance on delivery as well as inducing the drivers to work efficiently. Driver wages on second shift work have an hourly increment, paid for the standard hours worked.

Truck loaders are paid on a similar incentive basis, so that the actual times required for loading and making deliveries are stable and well known. For the purposes of this study the entire operation of loading,

driving, unloading and return to plant may be treated as a single delivery operation, with " variable " wage costs well determined in terms of incentive rates and standard times for the operation.

Other variable costs and fixed charges are determined in accordance with standard accounting procedures.

The variable costs for delivery by common carrier, i.e., the charge made for delivery, are regulated by the State Public Utilities commission and determined from standard rate tables. Details of these tables will not be described here, but it is important to indicate that the charges do not follow closely the direct costs for making the individual deliveries.

Fixed charges for deliveries by common carrier include the costs of the traffic department devoted to placing orders, receiving billings and making payment for use of common carrier. A special staff is devoted to this work.

The fixed charges of operating the private truck fleet and using common carrier will depend upon the size of the private fleet, and ample cost data exists to estimate the variations of these fixed costs with size of private fleet.

As an indication of the scale of delivery activity, the total costs of delivery, both private fleet and common carrier, ran about $1,000,000 annually, divided about evenly between private fleet operation and common carrier. The company owns 26 trailer trucks.

By use of near optimum scheduling practices it is estimated conservatively that 5 to 10 per cent savings or $50,000 to $100,000 can be gained, and these savings are expected to be increased as the manufacturer adjusts his fleet to approximately optimum size.

2. the cost function for deliveries

For a given company fleet size N, consider a particular day, arbitrarily, and let:

(1) $K_1(N)$ = daily prorated amount of annual fixed costs allocated or imputed to company fleet operations.

(2) $K_2(N)$ = daily prorated amount of annual fixed costs allocated or imputed to use of common carriers.

The quantity $K_1(N)$ is taken to include the daily base pay of company drivers as well as standard overhead items, while $K_2(N)$ includes only standard overhead items, and the proration is made without consideration of the daily variations of delivery activity. Thus, the supply of company drivers is not adjusted to the daily fluctuations of deliveries required and the assignments made between company truck and common carrier. Also, idle company drivers cannot be applied to other tasks, by union agreement, and their base pay may not be charged to other company operations.

For the ith delivery on the particular day ($i = 1, 2, \ldots n$), let:

(3) $C_1^i(N)$ = variable costs for first shift company delivery.

(4) $\hat{C}_1^i(N)$ = variable costs for second shift company delivery.

(5) C_2^i = variable costs for common carrier delivery.

The variable costs $C_1^i(N)$ and $\hat{C}_1^i(N)$ include incentive pay as well as operating costs chargeable directly to the delivery, and they are related by:

(6) $\hat{C}_1^i(N) = C_1^i(N) + R.T_i,$
$R > 0 \quad (i = 1, 2, \ldots n),$

where

(7) R = incremental second shift pay per hour, exclusive of incentive pay.

(8) T_i = total standard time, in hours, for a company truck to make the ith delivery on either shift.

The pro-rated fixed costs $K_1(N)$, $K_2(N)$ obviously depend upon company fleet size N. No distinction is made between the various units of the company fleet and the number of trucks N adequately measures fleet size.

The variable costs $\hat{C}_1^i(N)$ and $C_1^i(N)$ are taken to depend upon private fleet size N, because as N changes (historically or hypothetically) the mix of trucks in the company fleet may vary, possibly resulting in significantly different operating costs. In such case, the individual trucks are not distinguished, but only the average variable cost of delivery over the various fleet units is altered.

The variable costs C_2^i for common carrier delivery are fixed by the established rate structure and do not vary with N.

Total delivery costs for a particular day are calculated by:

(9) $$C(N) = K_1(N) + K_2(N) + \sum_{i=1}^{n} [C_1^i(N).\alpha_i + \hat{C}_1^i(N)\beta_i + C_2^i(1 - \alpha_i - \beta_i)]$$

where α_i, β_i are assignment variables satisfying

(10) $$\alpha_i = \begin{cases} 1 \text{ if a company truck on first shift is used} \\ 0 \text{ otherwise} \end{cases} \quad (i = 1, 2, \ldots n)$$

(11) $$\beta_i = \begin{cases} 1 \text{ if a company truck on second shift is used} \\ 0 \text{ otherwise} \end{cases} \quad (i = 1, 2, \ldots n)$$

(12) $$\alpha_i\beta_i = 0 \qquad (i = 1, 2, \ldots n)$$

(13) $$\sum_{i=1}^{n} \alpha_i T_i \leqq T(N)$$

(14) $$\sum_{i=1}^{n} \beta_i T_i \leqq \boldsymbol{T}(N)$$

The quantities $T(N)$ and $\boldsymbol{T}(N)$ denote the total number of delivery hours available per day on the first and second shift respectively, and they obviously depend upon private fleet size N.

Generally

(15) $$T_i \leqq \boldsymbol{T}(N) \leqq T(N)$$

with the inequality holding between $\boldsymbol{T}(N)$ and $T(N)$ if maintenance is done primarily on the second shift.

3. least cost assignment of deliveries

The optimum assignment of daily deliveries between private fleet and common carrier is given by those values of α_i, β_i satisfying (10), . . . (14) which minimize (9). In this optimisation the parameter N is treated as a fixed quantity, and for practical application fleet size will not be altered except at

predetermined intervals covering planning periods. However, the dependence of optimum scheduling upon fleet size must be known, if optimum fleet size is to be analysed.

This optimisation is not a simple linear programming problem ([1]), because of relations (12) and the discreet nature of the assignment variables as indicated by conditions (10) and (11). Recent work on integer solutions, ([2]) and ([3]) is not evidently applicable, not expeditious.

Recursion methods, described by Bellman as Dynamic Programming ([4]), have been suggested for problems of this type, but not investigated in detail to examine computational problems and feasibility of obtaining simple decision rules, albeit approximate. Since the scheduling has to be done daily and analysis of optimum fleet size involves calculations over many days (e.g., those during a past year) it is obviously important to obtain a simple rule for scheduling, although perhaps not mathematically exact, and, if an approximate rule is used, it is important to know a bound upon the deviation from true minimum cost thereby entailed.

For the treatment of the scheduling problem by dynamic programming it is convenient to reformulate the mathematical statement of the problem as follows:

Express the cost function (9) as:

$$(9.1)\quad C(N) = K_1(N) + K_2(N) + \sum_{i=1}^{n} C_2^i - \sum_{i=1}^{n} \left\{ [C_2^i - C_1^i(N)]\alpha_i + [C_2^i - \hat{C}_1^i(N)]\beta_i \right\}$$

from which it may be seen that the minimum of (9) may be obtained by maximising:

(16)

$$S(N) = \sum_{i=1}^{n} \{ [C_2^i - C_1^i(N)]\alpha_i + [C_2^i - \hat{C}_1^i(N)]\beta_i \}$$

The first three terms of the equivalent cost function (9.1) represent daily delivery costs if common carrier is used for all deliveries, and the maximum of expression (16) represents the savings which can be made by optimum assignment of deliveries to company trucks.

Next make a change of variables by defining:

$$(17)\qquad X_i = \alpha_i T_i \qquad (i = 1, 2, \ldots n)$$
$$(18)\qquad Y_i = \beta_i T_i \qquad (i = 1, 2, \ldots n)$$

and write (16) as:

$$(16.1)\qquad S(N) = \sum_{i=1}^{n} (A_i X_i + B_i Y_i)$$

where

$$(19)\qquad A_i = \frac{C_2^i - C_1^i(N)}{T_i} \quad (i = 1, 2, \ldots n)$$

$$(20)\qquad B_i = \frac{C_2^i - \hat{C}_1^i(N)}{T_i} \quad (i = 1, 2, \ldots n)$$

Then the optimum daily assignment of deliveries is given by values of X_i, Y_i which maximise (16.1) and satisfy

$$(10.1)\quad X_i = \begin{cases} T_i & \text{if company truck on first shift is used} \quad (i = 1, 2, \ldots n) \\ 0 & \text{otherwise} \end{cases}$$

$$(11.1)\quad Y_i = \begin{cases} T_i & \text{if company truck on second shift is used} \quad (i = 1, 2, \ldots n) \\ 0 & \text{otherwise} \end{cases}$$

$$(12.1)\quad X_i Y_i = 0 \qquad (i = 1, 2, \ldots n)$$

$$(13.1)\qquad \sum_{i=1}^{n} X_i \leqq T(N)$$

$$(14.1)\qquad \sum_{i=1}^{n} Y_i \leqq \boldsymbol{T}(N)$$

The mathematical formulation of the daily scheduling problem is now in a form convenient for study by dynamic programming. In this study, to follow, it is important to observe the special structure of the function (16.1) which is to be maximised, if a simple rule is to be found. Mathematical details will be discussed in the next section, showing that an exact calculation is prohibitive, and a simple approximate scheduling rule will be developed with a bound given on the deviation from the maximum value of (16.1) thereby entailed. Then in a following section this rule will be stated in simple operational terms. Finally the analysis of optimum fleet size will be discussed. The non-mathematically interested reader may skip the next section and proceed to the following paragraphs.

4. mathematical details

The coefficients A_i, B_i represent differential variable costs per unit of common carrier delivery over private fleet delivery for first and second shift private fleet operation respectively, and the special structure of the objective function (16.1) may be observed by noting that, if the deliveries are ordered so that:

$$(21)\qquad A_1 \geqq A_2 \geqq A_3 \ldots \geqq A_n$$

the resulting order of the coefficients B_1 is such that

$$(22)\qquad B_1 \geqq B_2 \geqq B_3 \ldots \geqq B_n$$

because, by virtue of (6), (19), (20) and (21),

$$(23)\quad B_i = \frac{C_2^i - \hat{C}_1^i(N)}{T_i} = \frac{C_2^i - C_1^i(N)}{T_i} - R$$
$$= A_i - R \geqq A_{i+1} - R = B_{i+1}$$

Also, with this ordering

$$(24)\qquad A_i > B_i \qquad (i = 1, 2, \ldots n)$$

since $A_i = B_i + R$ and $R > 0$. Hereafter, the daily deliveries will be assumed to be ordered so that (21) and (22) hold, as well as (24).

Now, to return to the solution structure of the assignment problem as one of dynamic programming, define for any positive integer k $(1 \leqq k \leqq n)$

(25) $f_k(T(N), \boldsymbol{T}(N)) =$

$$\max_{\substack{(X_i Y_i) \\ i=1,2,\ldots k}} \left[\sum_{i=1}^{k} (A_i X_i + B_i Y_i)\right] \qquad (k = 1, 2, \ldots n)$$

with the variables X_i, Y_i $(i = 1, 2, \ldots k)$ restrained to equations (10.1) . . . (14.1) in which n is replaced by k. Starting with f_1, the functions of f_k may be computed recursively until f_n is obtained, and the values found for X_i, Y_i $(i = 1, 2, \ldots n)$ corresponding to f_n define the optimum assignment of deliveries between private fleet and common carrier. Hopefully, each function f_k and the corresponding assignments X_i, Y_i $(i = 1, 2, \ldots k)$ may be determined from that made for f_{k-1}, starting with f_1 and progressing to f_n, with less effort than is required to determine the optimum assignment for n deliveries without examining the dependence of the solution upon the number of deliveries. If there is a simple rule for assignment of deliveries, it is expected that such a rule may be displayed by a recursive calculation which traces the effect of the number of orders n. Also the effect upon the solution, as boundary conditions, of having $T(N)$ and $\boldsymbol{T}(N)$ delivery hours available with the private fleet on first and second shift, may be examined simultaneously.

The general structure of this recursive calculation may be expressed as follows:

For each positive integer k satisfying $(1 \leqq k \leqq n)$ let

(26) $X_i^{(k)}[T(N), \boldsymbol{T}(N)]; \quad Y_i^{(k)}[T(N), \boldsymbol{T}(N)]$
$(i = 1, 2, \ldots k)$

denote the values of X_i, Y_i determining $f_k[T(N), \boldsymbol{T}(N)]$. These values may depend upon the number of deliveries k and delivery hours $T(N)$, $\boldsymbol{T}(N)$ available with the private fleet, and this dependence is so indicated. Then we may represent $f_k[T(N), \boldsymbol{T}(N)]$ recursively in terms of $f_{k-1}[T(N), \boldsymbol{T}(N)]$ by

(27) $f_k[T(N), \boldsymbol{T}(N)]$
$$= \max_{(X_k Y_k)} \{A_k X_k + B_k Y_k + f_{k-1}[T(N) - X_k, \boldsymbol{T}(N) - Y]\}$$

with the variable pair X_k, Y_k restrained in this maximisation to satisfy

(10.2) $$X_k = \begin{cases} T_k \\ 0 \end{cases}$$

(11.2) $$Y_k = \begin{cases} T_k \\ 0 \end{cases}$$

(12.2) $$X_k Y_k = 0$$

(13.2) $$X_k \leqq T(N) - \sum_{i=1}^{k-1} X_i^{(k-1)}[T(N) - X_k, \boldsymbol{T}(N) - Y_k]$$

(14.2) $$Y_k \leqq \boldsymbol{T}(N) - \sum_{i=1}^{k-1} Y_i^{(k-1)}[T(N) - X_k, \boldsymbol{T}(N) - Y_k]$$

where the quantities $X_i^{(k-1)}[T(N) - X_k, \boldsymbol{T}(N) - Y^k]$, $Y_i^{(k-1)}[T(N) - X_k, \boldsymbol{T}(N) - Y_k]$. $[i = 1, 2, \ldots (k-1)]$ determining $f_{k-1}[T(N) - X_k, \boldsymbol{T}(N) - Y_k]$ are solutions of (25) for $(k-1)$, using the restraints (10.1) . . . (14.1) with n replaced by $(k-1)$ and the right sides of (13.1) and (14.1) replaced by $[T(N) - X_k]$ and $[\boldsymbol{T}(N) - Y_k]$ respectively.

It is clear, from the linear nature of the right side of (25) and resulting separability of variables, that if

(28) $$\sum_{i=1}^{k} T_i \leqq \boldsymbol{T}(N) \leqq T(N)$$

equation (27) may be simplified to:

(27.1) $$f_k[T(N), \boldsymbol{T}(N)] = f_{k-1}[T(N), \boldsymbol{T}(N)] + \max_{(X_k, Y_k)} (A_k X_k + B_k Y_k)$$

because the solutions $X_1^{(k-1)}$, $Y_1^{(k-1)}$ $[i = 1, 2, \ldots (k-1)]$ defining f_{k-1} will not depend upon X_k and Y_k, since the restraints (13.1) and (14.1) (with n replaced by k) are not effective. Neither are the restraints (13.2) and (14.2) effective for the maximisation with respect to the variable pair X_k, Y_k indicated in the second term on the right side of (27.1). Then, up to the largest positive integer k for which (28) holds, the calculations of the functions f_k $(k = 1, 2, \ldots k)$ and resulting optimum assignments X_i, Y_i $(i = 1, 2, \ldots k)$ are particularly simple. Specifically, due to the inequalities (21), (22), (24) and the restraints (12.1),

(29) $$f_v[T(N), \boldsymbol{T}(N)] = \sum_{i=1}^{v} \partial_i A_i T_i;$$
$$\partial_i = \begin{cases} 1 \text{ if } A_i > 0 \\ 0 \text{ if } A_i \leqq 0 \end{cases}$$
$$(v = 1, 2, \ldots k)$$

and the corresponding optimising values of the quantities X_i, Y_i are

(30) $$X_i = \partial_i T_i; \qquad Y_i = 0$$
$$(i = 1, 2, \ldots v) \text{ for } (v = 1, 2, \ldots k)$$

It may be noted that for this simplification condition (28) may be weakened by dropping the middle term, because due to (24), no assignment to second shift private fleet delivery will be made in preference to a first shift delivery, when the applicable $A_i > 0$, and neither will $B_i > 0$ when $A_i \leqq 0$.

If condition (28) (with middle term omitted) holds for k equal to n, the solution of the problem of assigning deliveries between private fleet and common carrier is simple and immediate. It is given by:

(31) $$\alpha_i = \partial_i, \qquad \beta_i = 0 \qquad (i = 1, 2, \ldots n)$$
$$\partial_i = \begin{cases} 1 \text{ if } A_i > 0 \\ 0 \text{ if } A_i \leqq 0 \end{cases}$$

obtained from (30) by putting $k = n$ and using (17) and (18). The corresponding cost of making the n deliveries for the particular day considered is

(32) $$C(N) = K_1(N) + K_2(N) + \sum_{i=1}^{n} (\partial_i C_1^i(N) + (1 - \partial_i) C_2^i)$$

If condition (28) (with middle term omitted) fails for k equal to n, but holds for some positive integer v_2 such that

$$v_2 \geqq v_1 \tag{33}$$

where v_1 is a positive integer for which

$$A_{v_1} > 0, \qquad A_{v_1+1} \leqq 0 \tag{34}$$

then the solution (31) still holds. This conclusion is verified as follows: since $A_{v_1+1} \leqq 0$, it follows from (21) that all succeeding coefficients A_i will be non-positive, and from (24) it follows that $B_i < 0$ when $(i = v_1 + 1, v_1 + 2, \ldots n)$. For these non-positive coefficients, it is clear that the maximum of the sum in (16.1) requires that the corresponding factors X_i, Y_i $(i = v_1 + 1, v_1 + 2, \ldots n)$ uniformly take the admissable zero values. Hence the maximum of (16) becomes:

$$\max_{\substack{X_i,\ Y_i \\ (i=1,\,2,\,\ldots\,n)}} S(N) = f_{v_1}[T(N), \boldsymbol{T}(N)]$$

and the simplified form (27.1) may still be used for $f_{v_1}[T(N), \boldsymbol{T}(N)]$, because (28) holds for k equal to v_1. Consequently, the solution (31), (32) still holds. We need only observe that:

$$\begin{aligned} \partial_i &= 1 \quad \text{for} \quad (i = 1, 2, \ldots v_1), \\ \partial_i &= 0 \quad \text{for} \quad (i = v_1 + 1, \ldots n) \end{aligned} \tag{35}$$

If the largest integer for which (28) holds (with middle term omitted) say v_2, is such that:

$$v_2 < v_1 \tag{33.1}$$

where v_1 is an integer for which (34) is obtained, our difficulties commence in getting the optimum assignment of deliveries. Under these circumstances we are required to use the more complicated form (27) in the calculation of the functions f_k for $(v_2 < k \leqq v_1)$, necessitating for each k in this interval a re-examination of the assignments made previously for f_{k-1}, treating these assignments as well as the function f_{k-1} as dependent upon X_k, Y_k. It is possible, for example, to increase the value of f_{v_2+1} over what it would be if X_{v_2+1} were taken zero and Y_{v_2+1} were taken equal to T_{v_2+1}, by taking $X_{v_2+1} = T_{v_2+1}$ and putting one or more values of X_i equal to zero with corresponding $Y_i = T_i$ for $i = v_2$, supposing throughout that the alternatives employed do not violate the applicable form of the restraints (13.1) and (14.1). The examination of all of these possibilities, successively, for all values of k in the interval $(v_2 < k \leqq v_1)$ is complicated and not obviously warranted by the increase in the value of $S(N)$ thereby obtained, especially in view of the approximate validity of the values of the coefficients A_i, B_i, which in any application are at best estimates of the cost parameters defining the actual practical situation studied.

approximate solution

Instead of pursuing the exact optimum assignment of deliveries between private fleet and common carrier, we may seek an approximate solution consistent with a simple rule for assignment of deliveries, provided the diminution of the maximum value of $S(N)$ thereby sustained is kept within a small bound.

First, we may observe that there is no advantage to using second shift deliveries in place of first shift deliveries, because of (24), unless the loss entailed is more than offset by the savings to be derived from using unallocated first shift time which is thereby accomplished. The potential gain to be obtained by such substitutions for all iterations in the interval $(v_2 < k \leqq v_1)$ is bounded by:

$$A_{v_2+1}[T(N) - \sum_{i=1}^{v_2} T_i] \tag{36}$$

This bound is verified as follows: the unused first shift time for the assignments yielding f_{v_2} equals the bracket in (36) and for all succeeding functions $f_k(v_2 < k \leqq v_1)$ substitutions of assignments between first and second shift cannot provide additional use of first shift time beyond this amount. Also the largest possible saving per unit time for this unallocated first shift time is given by the coefficient A_{v_2+1}, due to the inequalities (21), (22) and (24). Consequently the bound (36) holds.

Hence, with a loss which is at most given by (36), the unused first shift time related to the assignments defining f_{v_2} may be ignored for all subsequent calculations of the functions f_k for $(v_2 < k \leqq v_1)$.

Having made this approximation, we may use the assignments (31), with n replaced by v_2, for first shift deliveries, and proceed to examine separately the profitable assignments of deliveries to second shift private fleet operation. Because of (21), (22) and (24), there will be an integer $\mu_1 < v_1$ such that:

$$B_{\mu_1} > 0, \qquad B_{\mu_1+1} \leqq 0 \tag{34.1}$$

Then for integral values of k in the interval $(v_2 < k \leqq n)$, equation (25) may be written approximately as:

$$f_k[T(N), \boldsymbol{T}(N)] = f_{v_2}[T(N), \boldsymbol{T}(N)] + \max_{\substack{Y_i \\ (i=v_2+1,\,\ldots\,k)}} \left[\sum_{i=v_2+1}^{k} B_i Y_i\right] \tag{25.1}$$

where the variables Y_i satisfy (11.1) and are restrained to

$$\sum_{i=v_2+1}^{k} Y_i \leqq \boldsymbol{T}(N) \quad \text{for} \quad (K = v_2 + 1, \ldots n) \tag{37}$$

This separate treatment of second shift deliveries is made with an error from the true maximum of (16.1) which is bounded by expression (36).

If $\mu_1 \leqq v_2$, no assignment of second shift deliveries is profitable and the solution of the scheduling problem is given by:

$$\begin{aligned} &\begin{cases} \alpha_i = 1 \\ \beta_i = 0 \end{cases} \quad \text{for} \quad (i = 1, 2, \ldots v_2), \\ &\begin{cases} \alpha_i = 0 \\ \beta_i = 0 \end{cases} \quad \text{for} \quad (i = v_2 + 1, \ldots n) \end{aligned} \tag{31.1}$$

If $\mu_1 > v_2$ and condition (37) holds for $Y_i = T_i$ and $k = \mu_1$, the exact computation of the functions $f_k[T(N), \boldsymbol{T}(N)]$ given by (25.1) is immediate for the

range $(v_2 < k \leqq n)$, since, by virtue of (22), the assignments of second shift deliveries maximising the second term on the right side of (25.1) are evidently:

$$(38)\quad \beta_i = \Delta_i \quad (i = v_2 + 1, \ldots k), (k = v_2 + 1, \ldots n),$$
$$\Delta_i = \begin{cases} 1 & \text{if } B_i > 0 \\ 0 & \text{if } B_i \leqq 0 \end{cases}$$

Then the solution of the scheduling problem is given by:

$$(31.2)\quad \begin{cases} \alpha_i = 1 \\ \beta_i = 0 \end{cases} \text{ for } (i = 1, 2, \ldots v_2);$$
$$\begin{cases} \alpha_i = 0 \\ \beta_i = \Delta_i \end{cases} \text{ for } (i = v_2 + 1, \ldots n)$$
$$\Delta_i = \begin{cases} 1 & \text{if } B_i > 0 \\ 0 & \text{if } B_i \leqq 0 \end{cases}$$

If the largest integer for which (37) holds with $Y_i = T_i$, say μ_2 is such that:

$$(39)\qquad v_2 < \mu_2 < \mu_1$$

then we encounter boundary difficulties similar to that described above for first shift deliveries. Again, to avoid the complications involved in the interests of a simple rule for scheduling, we may ignore the unused second shift time related to the assignments giving:

$$\max_{\substack{Y_i \\ (i = v_2+1, \ldots \mu_2)}} \left[\sum_{i=v_2+1}^{\mu_2} B_i Y_i \right]$$

and use

$$(31.3)\quad \begin{cases} \alpha_i = 1 \\ \beta_i = 0 \end{cases} \text{ for } (i = 1, 2, \ldots v_2)$$
$$\begin{cases} \alpha_i = 0 \\ \beta_i = 1 \end{cases} \text{ for } (i = v_2 + 1, \ldots \mu_2)$$
$$\begin{cases} \alpha_i = 0 \\ \beta_i = 0 \end{cases} \text{ for } (i = \mu_2 + 1, \ldots n)$$

as an approximate solution to the scheduling problem. This approximation is made with a decrease from the maximum value of (16.1) which is bounded by:

$$(40)\qquad B_{\mu_2+1} \left(\boldsymbol{T}(N) - \sum_{i=v_2+1}^{\mu_2} T_i \right)$$

The foregoing arguments may be summarised by the following theorem:

Order the deliveries so that the cost coefficients A_i, B_i satisfy:

$$A_1 \geqq A_2 \geqq A_3 \ldots \geqq A_{n-1} \geqq A_n$$
$$B_1 \geqq B_2 \geqq B_3 \ldots \geqq B_{n-1} \geqq B_n$$

Let v_1 be an integer such that $A_{v_1} > 0$ and $A_{v_1+1} \leqq 0$

v_2 be the largest integer k such that $\sum_{i=1}^{k} T_i \leqq T(N)$, $(0 \leqq k \leqq n)$

$v^* = \min(v_1, v_2)$

μ_1 be an integer such that $B_{\mu_1} > 0$ and $B_{\mu_1+1} \leqq 0$ $(\mu_1 \leqq v_1)$

μ_2 be the largest integer $k > v^*$ such that $\sum_{i=v^*+1}^{k} T_i \leqq \boldsymbol{T}(N)$

$$\mu^* = \text{Min}(\mu_1, \mu_2)$$
$$w_1 = \begin{cases} 1 & \text{if } v^* = v_2 \neq v_1 \\ 0 & \text{if } v^* = v_1 \end{cases}$$
$$w_2 = \begin{cases} 1 & \text{if } \mu^* = \mu_2 \\ 0 & \text{if } \mu^* = \mu_1 \end{cases}$$
$$w_3 = \begin{cases} 1 & \text{if } \mu_1 > v^* \\ 0 & \text{if } \mu_1 \leqq v^* \end{cases}$$

Then, with an error from the minimum of total daily delivery costs bounded by:

$$(41)\qquad w_1 A_{v^*+1} (T(N) - \sum_{i=1}^{v^*} T_i) +$$
$$+ w_1 w_2 w_3 B_{\mu^*+1} \left(\boldsymbol{T}(N) - \sum_{i=v^*+1}^{\mu^*} T_i \right)$$

approximately optimal assignments of daily deliveries are given by:

(I) when $\mu_1 \leqq v^*$

$$(42)\quad \begin{cases} \alpha_i = 1 \\ \beta_i = 0 \end{cases} \text{ for } (i = 1, 2, \ldots v^*)$$
$$\begin{cases} \alpha_i = 0 \\ \beta_i = 0 \end{cases} \text{ for } (i = v^* + 1, \ldots n)$$

(II) when $\mu_1 > v^*$

$$(43)\quad \begin{cases} \alpha_i = 1 \\ \beta_i = 0 \end{cases} \text{ for } (i = 1, 2, \ldots v^*)$$
$$\begin{cases} \alpha_i = 0 \\ \beta_i = 1 \end{cases} \text{ for } (i = v^* + 1, \ldots \mu^*)$$
$$\begin{cases} \alpha_i = 0 \\ \beta_i = 0 \end{cases} \text{ for } (i = \mu^* + 1, \ldots n)$$

and total delivery cost is given by:

$$(44)\qquad C(N) = K_1(N) + K_2(N) +$$
$$+ \sum_{i=1}^{v^*} C_1{}^i(N) + w_3 \sum_{i=v^*+1}^{\mu^*} \hat{C}_1{}^i(N) +$$
$$+ (1 - w_3) \sum_{i=v^*+1}^{\mu^*} C_2{}^i + \sum_{i=\mu^*+1}^{n} C_2$$

5. the approximate scheduling rule

For each delivery during a particular day compute the coefficients:

$$A_i = \frac{C_2{}^i - C_1{}^i(N)}{T_i} \quad (i = 1, 2, \ldots n)$$

for the first shift delivery, and also the coefficients:

$$B_i = \frac{C_2{}^i - \hat{C}_1{}^i(N)}{T_i} \quad (i = 1, 2, \ldots n)$$

for second shift delivery. These coefficients represent differential variable costs per unit time of common carrier delivery over private fleet delivery for first and second shift private fleet operation respectively.

Then array the deliveries in descending order or algebraic magnitude of the coefficients A_i. The array

so found will also be one for which the coefficients B_1 are likewise in descending order of algebraic value.

Schedule the deliveries so arrayed to first shift company truck delivery if the corresponding coefficient A_t is positive, up to that delivery where no further first shift capacity exists. If all deliveries can be so scheduled on the first shift the work is finished. If not, proceed to schedule the deliveries on the second shift for all those for which the corresponding coefficient B_t is positive, or until second shift capacity is fully utilised. Those deliveries not so scheduled to either first or second shift as a company delivery are to be assigned to common carrier.

The foregoing approximate scheduling rule deviates from a true minimum cost only when there is a delivery for either first shift or second shift company delivery, with positive coefficient A_t or B_t, which cannot be met by the unscheduled company delivery time available. This deviation is bounded by the product of the unscheduled time and the corresponding coefficient A_t or B_t. Evidently these quantities are a small part of total costs, being less than the excess of the costs of common carrier delivery over the variable costs of private fleet delivery, for only the two deliveries involved.

6. optimum fleet size

The notion of optimum fleet size has useful operational meaning only with respect to some specific planning period, because orders for delivery are neither stationary over time nor controllable by the supplier. Preferably this period of time should be compatible with an estimation or computation of cost factors and an orderly alteration of fleet size. If the estimations reflect operating conditions and are not forecasts, the planning period will be one in retrospect, say the past year of operation. During such a period, and likewise for a future period, deliveries will vary considerably from day to day, in both number (n) and relative profitabilities A_t, B_t. The total costs of operation for the year, for any hypothetical fleet size N, are given by an annual sum of daily costs given by expressions like (9.1). Consequently a comparison of total costs, in retrospect, for various alternative fleet sizes N, cannot be made rationally without an internal daily decision rule for optimum assignment of deliveries between private truck and common carrier, and this rule will depend upon N, as well as the number of deliveries (n) and the profitability coefficients A_t, B_t for each day.

The approximate recursive solution given in the previous section is naturally adapted to this problem, and the simple rule provided will enable a tabulation of total delivery costs as a function of fleet size N, from which a cost minimising value of N may be estimated. Then purchase or retirement of private fleet trucks may be made from one retrospective planning period to the next, as a control on the total costs of making local deliveries. The control thus obtained will be comparatively close to a minimum for delivery costs, provided the average daily number and character of deliveries do not fluctuate violently from one planning period to the next.

If the annual variation is great, the problem of optimising fleet size may be complex indeed, because forecasts of average daily volume alone are not sufficient. Changes in the average composition (i.e., the cost coefficients A_t, B_t) will also have to be forecasted, unless the annual sum of the daily maximum values of expression (16) is a small part of the annual sum of the daily values of expression (9.1), in which case the optimum fleet size N is close to zero and the adjustment of fleet size is more or less academic.

Regardless of how well an optimum fleet size can be determined, it is important to have an optimum daily decision rule for assignment of deliveries between private truck and common carrier. The operating decision to be made arises day by day, no matter how well the decision for investment in company trucks has been made, and considerable funds may be at stake.

7. remarks on recursive solutions of scheduling problems

The possible advantages of a recursive method of solution over a linear programming approach to scheduling problems are well illustrated by the foregoing analysis. When the items to be scheduled vary considerably from one decision period to the next and the optimum assignment thereby changes, a short and highly repetitive decision period will make unfeasible an application of linear programming, because of the large volume of complex calculations thereby required, particularly when the variables involved have the usual discreet character.

Recursive methods, which have come to be known as dynamic programming, due to the work of Bellman, offer the best opportunity for analysis, since the dependence of the solution upon the number of items to be scheduled, and other significant parameters like fleet size N in the present problem, can be investigated. But often such solutions, if exactly made, involve a tremendous volume of calculation — no less than that of linear programming. What is needed then, is more careful study of the structure of the function to be optimised, and the use of good approximate solutions which execute the essential features of the optimisation and provide simple decision rules for operation.

In the problem at hand, the dependence of the solution upon fleet size N, which is important for the study of optimum fleet size, is clearly exhibited. Starting with N small, relative to the number of deliveries (n) and numbers ν_1, μ_1 of profitable deliveries by private fleet, and assuming that ν_1 and ${}_1\mu$ are generally non-zero (which is reasonable because otherwise the optimum fleet size is zero and we have no problem), deliveries will be made on both first and second shift up to the capacity of the private fleet, with assignments made consecutively for the deliveries ordered so that relations (21) and (22) hold. Then as N is increased, more deliveries will be made on first shift, with second shift deliveries decreasing to zero, in accordance with relations (42) and (43), until eventually there is excess private fleet capacity on the first shift for profitable deliveries and thereafter the assignments are unaffected by fleet size. On this

basis, a calculation of the relation between total annual delivery costs and fleet size can be made by summing the costs for daily optimum assignments. The use of the approximate solution, summarised in the theorem of Section 4, is clearly justified, and the maximum possible error from minimum cost thereby engendered may be determined from expression (41) and balanced against the accuracy of the input data used.

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BRITISH CONFERENCE ON AUTOMATION AND COMPUTATION

"AUTOMATION - MEN and MONEY"

to be held from 27th - 30th June, 1961

This Conference will be of interest to all in the general management and specialist fields in industry and commerce. It is to be sponsored by those bodies which form the membership of Group "C", a sub-committee of B.C.A.C.:

The British Institute of Management
Department of Scientific & Industrial Research
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The Trades Union Congress
Institute of Personnel Management
Tavistock Institute of Human Relations

The programme will be of three days' duration, commencing with a plenary session and reception in the evening of the opening day, and concluding with a second plenary session in the morning of the final day. It is proposed to hold sectional meetings in the morning of each day, and that these will take the form of four series of meetings running in parallel.

The final plenary session will consist of an address by Sir Walter Puckey, Past President of the Institution of Production Engineers.

Further details of the programme will be announced as they become available.

THE VALUE OF
THE CONTROL OF PRODUCT QUALITY

by F. NIXON, B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E., M.I.Prod.E.

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A Paper presented to the E.O.Q.C. Conference held in London, 1st - 3rd September, 1960.

"NO man's opinons are better than his information." That was said by Jean Paul Getty when he was asked not long ago what had contributed to his outstanding success in the business world.

The method followed by Mr. Getty is, in fact, that which is the fundamental basis of the Control of Product Quality — obtain the best and most reliable information possible, use it to arrive at a decision, and take action accordingly.

This has been appreciated and put to effective use already by some firms in Britain — large firms on the whole, and occupied in the main in the process industries. Abroad, particularly in the United States, Japan and India, its adoption has been wider. Indeed, in the United States formal methods of Quality Control are a Government requirement for all contractors.

All these concerns are hard-headed, and if they have realised that they cannot afford to be without Quality Control, how much less can all those thousands of smaller firms, who in the aggregate constitute by far the greater portion of industry?

This is a matter of vital importance, not only to the firms themselves, who are ignoring an easy and effective way of reducing their production costs, but also to the large firms who depend upon the smaller firms, often upon large numbers of them, working either as sub-contractors, or as suppliers of some special piece of equipment. Indeed, it is not going too far to say that the prosperity and the safety of a nation depend upon the quality-mindedness of its industry as a whole.

Only three months ago the Federation of British Industries showed how the further expansion of industry was being limited by the shortage of skilled labour, and by rising production costs. The existing labour force can be made more productive, and costs can be lowered, simply by ensuring that a greater proportion of the output is made correctly the first time. When it is realised that our direct production operatives are each making between £100 - £300 worth of spoilt work per annum, priced at Factory Cost, we can see what can be achieved by controlling product quality.

This Paper is addressed therefore to those who are responsible for that depressingly large proportion of industry which has, as yet, failed to recognise the value of the control of the quality of its products.

the present situation

Why is it that this situation exists?

Many of the large firms whose names are household words have been practising Quality Control for years.

The pioneers of 30-odd years ago, Dr. Dudding, of the General Electric Company in Great Britain, and Dr. Shewhart, of the Bell Telephone Company in the United States, stated the case simply and clearly enough. Dr. Dudding said that Quality Control was 95% an attitude of mind, and Dr. Shewhart reiterated the important part played by the intuition and judgment of the engineer.

Unfortunately, as it has turned out, many of the early successes of Quality Control were in fields in which statistical methods were able to play an outstanding part. Applications to the control of the dimensions of machined parts being produced in large numbers, to cartridge cases produced in millions, and to the control of continuous processes, as in the brewing, oil, chemical and textile industries, were so successful that their practitioners tended to overlook these earlier dicta. Flushed with their success, they were inclined to consider the statistical means as the universal panacea. Quality Control, and Statistical Quality Control, became synonymous, and valuable as it can be, in the right circumstances, it is felt that undue emphasis upon S.Q.C. has militated against the earlier and wider application of the value of the control of product quality in its true sense.

If we consider for a moment industry as a whole, we find that 98% of the firms engaged in manufacturing in the United Kingdom employ fewer than 1,000 people. Many of them are engaged mainly or wholly in batch production. Nearly all of them are suffering from a serious shortage of technically-trained engineers. In quite a large number of them it will be found that the Chief Inspector is held of little account, since his function is looked upon as a necessary evil, quite definitely non-productive, if not in fact anti-productive.

To advocate that these firms should adopt statistical control methods, willy-nilly, is likely to produce an antipathetic reaction. The personnel, from Chief Inspector to Chief Executive, will certainly be extremely busy men. Their mathematics will be rusty, if not actually corroded through, and there will be the natural suspicion that here is a cranky method which cannot fail to increase the overheads.

It is indeed unfortunate that this emphasis on statistics has blinded so many people to the essential need, in every business enterprise, for the collection of accurate information on which to base appropriate action. This is the essence of Quality Control, in which statistical methods can sometimes be a useful tool. Where their use is appropriate, it will usually be found that simple Do-It-Yourself statistical methods will suffice for most purposes.

the control of product quality

The full control of product quality, however, is a much wider matter than has been suggested by the advocates of statistical quality control.

It is proposed to consider first why there is this urgent need for Quality Control, then to describe what it is in the present concept, how to implement it, and what returns can be expected from its adoption.

why is it necessary to control product quality ?

Every manufactured product, no matter to what extent the production process may have been automated, depends at some stage upon the efforts of individuals. And just as no two individuals are ever exactly alike, so also no two manufactured products will ever be identical. The individual components of any production batch will vary, sometimes predictably, sometimes unpredictably.

It is in his appreciation of the inevitability of variability in the product, and in proffering methods for the detection, the study and the control of that variability, that the statistician has rendered such signal service. It was once sufficient to leave the control of this variability to the craftsman, and it is interesting to look back upon the efforts of the Craft Guilds, which were amongst the early practitioners of Quality Control, and indeed more largely concerned with setting standards of training and performance which would maintain their trade in good repute. As it is understood today, however, the Control of Product Quality requires a discipline and an organised approach which have been made necessary by modern conditions in industry.

The struggle for markets has led to a great increase in the rate of introduction of new designs of product, and great pressure is put upon all concerned to produce at a lower price than one's competitors. Gone are the days when a design, having reached a satisfactory stage of development, remained in series production for several years, so that the skilled personnel engaged in its manufacture could become thoroughly experienced, and the reputation gained was quite sufficient to maintain an adequate order book.

Today, one design suceeds another with bewildering rapidity. Each must be tooled and in production in the minimum time in order to catch the market. Considerations of economy as well as the enormous increase in the scale of manufacturing industry have led to heavy dilution of the skilled labour formerly employed. And, finally, the intensified competition as underdeveloped countries become increasingly industrialised and enter the field means that, more than ever before, regard must be paid to the economies of manufacture.

All this has resulted in a greatly increased tempo. No longer is there time available to get into the swing. Maximum economy and maximum efficiency must be attained as quickly as possible, and maintained throughout the production run, despite the fact that the labour is less skilled, and that it is continually being confronted with new problems and techniques.

The solution is to have an organised approach to the problem, in parallel with the other organised disciplines which have been adopted by progressive managements, and it is here that Control of Product Quality is able to make such a valuable contribution.

what do we mean by the control of product quality ?

It is a pity that there is no satisfactory alternative to the word "quality". Dr. Lüsser, a leading German authority, prefers "reliability", but the overall aspect of the concept must carry with it the connotation of *value*. Hence we are considering today the Control of Product Quality in its broadest sense, as a practice which has as its objective the achievement of requisite quality of product, at minimum cost.

This last phrase describes the prime purpose of every industrial organisation. Let us examine in detail what it involves.

Requisite quality is taken to mean that level of quality which will satisfy the customer, at the price which he is called upon to pay. No one who is in business for profit desires to give the customer more than he has paid for. Equally, no one who wishes to remain in business can afford to sell to the customer any product which fails to come up to the level of satisfaction which he expects.

So the first task is to determine the acceptable quality level — the requisite quality.

This is a most important matter and it will be one of more or less difficulty, depending upon the nature of the product. At one extreme it may involve the amount and condition of sugar in a packet; at the other, the integrity of a highly-stressed component of an aircraft engine, or the reliability of a complex electronic component of a guided weapon system. In all cases there will be a minimum level below which the quality must not fall. To ensure that each and every packet of sugar which is filled, that each and every engine or weapon component which is produced, reaches that level, requires a study of the way in which the product is likely to vary during manufacture.

Statistical methods can be of great value here, but their use is not mandatory. A rough and sensible guide has been given by Mr. R. C. Trundle [1]: "Where the value of a piece is high, the chance for error great, and the operation not continuous, statistical control may not be justified. On the other hand, when there is but slight chance for error, a steady flow of parts, and a difficult inspection job, statistical control will generally prove to be economical."

Let it be said at once however, that statistical methods can still be of value in the first case, to help to diagnose causes of trouble.

Whatever means are employed, the first need is to lay down a clear and adequate specification of the requisite quality. It is here that the statistician can be of great service, not necessarily by proffering a statistical method of analysis or of control, but rather by demonstrating his mode of thinking. Long ago he talked of the A.Q.L. (Acceptable Quality Level) and he has been thoroughly conditioned to thinking in terms of variability. What the manufacturer needs to do is to extend this thinking from quantitative attributes such as the dimensions of machined parts to such qualitative attributes as appearance, finish, soundness and life as well.

Having established the requisite quality, or the A.Q.L., customer satisfaction is maintained by ensuring that no product which fails to reach that level is allowed to leave the factory. This is the responsibility of inspection.

By itself, however, this is not enough, as no account has yet been taken of the importance of achieving this objective at minimum cost. It is here that the Control of Product Quality in the modern concept plays its second important role. The study of the causes of variability and the reduction of the variability to the optimum level, can bring about considerable savings by reducing the amount of rejected work, and of rework of defective parts. There can be little doubt that any industrial executive who will take the trouble to ascertain accurately the cast of scrap and rework in his organisation will, when he has recovered from the initial shock be determined to take action. Beating the table will usually bring about an immediate reduction, but it will also tend to drive the truth underground. A planned attack on the problem, along Quality Control lines, has been shown to be capable, time and again and in an extremely wide variety of industries, of effecting a permanent saving in cost of scrap and rework of at least 50% and often far more.

In addition to this great saving, however, there are other important benefits, such as increased reputation, improved customer relations, increased productivity, and increased operator interest, which will be dealt with later.

Most firms are anxious to achieve a reduction in cost, at the existing level. But increasingly these days we are concerned with reliability, whether it be of our motor car, our refrigerator, our television set, our telephone, or the military equipment used by the armed services, and the consequences to the manufacturer of failure to ensure reliability can be expensive, and sometimes fatal. As this equipment becomes more complicated, so does it become increasingly difficult to ensure that it will always perform as expected. In all these fields control of product quality plays a vital part. Reliability cannot exist without good design, but the best design will fail if the requisite quality is not achieved. Even the most advanced piece of equipment — a guided weapon say — may depend for successful overall performance upon the reliability of a number of essential detail components which are the products of small firms. The reliability of the whole depends upon the reliability of its constituent parts, and so it is essential that the whole of industry should be exercising control of product quality.

Obviously the effort to be expended upon all this must be related to the potential gains. Where the objective is the ultimate in performance or reliability, as in aircraft and military fields, technical and strategic rather than financial considerations may justify the means. In other cases, survival in the face of competition may be involved, and here again the

cost of the effort may be, for the time being, of secondary importance.

Conducted along the lines which will be described, however, the cost of exercising effective control of product quality is small, and in every case where figures are available, the savings have far outweighed it, sometimes in spectacular fashion.

how to control product quality

Industrial organisations vary as much as do their individual products, and for this reason it would be quite wrong to endeavour to offer a single formula for the introduction of Quality Control into industry in general. Dr. Juran has expressed this neatly by uttering a warning: "The temptation to start with remedies instead of diagnosis is so common that it merits separate discussion. The peril exists because many people are engaged in hard selling of remedies, but few are engaged in hard selling of diagnosis." 2 It is not going too far to say that much of the tardiness in taking up the control of product quality is due to unconscious sales resistance to the hard sellers of Quality Control.

The appropriate form of Quality Control which should be adopted by any individual organisation can only be determined as a result of intelligent diagnosis of the needs of that organisation. Accordingly, an effort has been made to provide a guide to those who may be inspired to endeavour to undertake their own diagnosis. This guide is given, in what are intended to be really general terms, in the chart at the end of this Paper.

It has been taken that the purpose of the organisation is the achievement of the requisite quality of product, at minimum cost.

Requisite quality is defined as that standard of reliability, or fitness for purpose in the product, which is necessary to ensure customer satisfaction.

The establishment of the standard of requisite quality will usually be a joint responsibility, shared in varying amounts, according to the constitution of the organisation, by the Executive, the Research, Design, Development, Manufacturing and Sales sides, and probably influenced in no small degree by the reputation, tradition and past performance of the Company.

Once the standard has been set, or has come into being by the establishment of a level of customer satisfaction based upon past performance, that standard can only be maintained consistently and economically by asserting control over all relevant aspects of the specification, the manufacture and inspection of the product.

This task will require action under the following headings:

1. ensuring that adequate specifications exist, which clearly define the acceptable quality level;
2. checking that the specified standards are met, which is in the main the responsibility of the Inspection Department as it is at present understood by most firms;
3. investigating and eliminating causes of non-conformance (which is done by some means or other, more or less effectively, in every organisation, but which here requires formalised and sustained action);
4. and all of the foregoing with constant regard to the economics of the exercise, that is, as cheaply as possible.

The exercise of full control of product quality will require the application of engineering, inspection of various kinds, proving (e.g., by testing), and statistical methods of analysing manufacturing performance, each in greater or lesser degree according to the nature of the product, its value, its purpose, the rate and scale of its production, the personality of the organisation and the capabilities of the personnel concerned.

There is no simple universal solution, nor any single ideal form or organisation. While full control will not be ensured unless and until provision has been made somewhere within the organisation for the continuous and effective performance of each and every one of the essential functions which have been summarised in the chart, it is generally wise to pay regard to the existing organisation, and to avoid making changes merely for the sake of change.

The firm which is already achieving a fairly satisfactory performance will probably find that it is already carrying out more of the functions than will be the case in a less successful firm.

The precise title under which each function is carried out is of no significance. In one small and highly efficient firm the setter is held responsible for any machining scrap arising. In another, larger, firm a Quality Control engineer is responsible for feeding back to production the information obtained from an analysis of a control chart maintained by an inspector.

In many people's minds great confusion exists regarding the respective functions and responsibilities of the inspector and the quality engineer. One of the most able quality engineers in England operates under the title of Chief Inspector. In another firm, the corresponding title is Director of Quality Control.

At the other extreme, cases are known of Chief Inspectors, who are little more than sorters of good from bad, changing their title, perhaps through fear of being considered old-fashioned, to that of Quality Control Manager, but without altering their habits in the slightest.

To assist in clearing up this confusion, an attempt has been made to indicate in the Chart those responsibilities which rightly belong to the Chief Inspector, and those which should be carried out by an independent body.

Briefly, the Chief Inspector is the man who is ultimately responsible for ensuring that no product is accepted which fails to conform to the specifications. He must have full authority to reject non-conforming parts. Equally he cannot, alone, accept under concession any parts which, though not to specification, may be considered satisfactory and

usable. Here, the authority of the Quality Engineer and the agreement of the Designer must be sought.

Functions which the Chief Inspector ought not to carry out are those which check the performance of his own department — for example, the Inspection Audit or the Quality Assurance check which was formerly such a valuable function of the Aeronautical Inspection Directorate.

The functions which remain unmarked in the Chart may be carried out by the Chief Inspector, but in the case of larger organisations it will usually be decided that the importance of the results to be obtained justifies the setting up of a separate Quality Department, to carry out these functions as a full-time responsibility.

It will help to repeat the definition which has been laid down by Mr. E. G. D. Paterson of Bell Telephone Laboratories, which have pioneered in Quality Control for more than 30 years past. He says that the shop inspector's function is the triple one of :

1. protecting the manufacturers' own interests;
2. aiding the smoother flow of production;
3. supplying evidence that he has met his responsibility as a reputable manufacturer to produce good quality.[3]

In contrast, the Quality Engineer, under whatever title he may operate, has the three-fold task of :

1. assessing what are the limits of variability permissible in the product;
2. assessing the variations in product quality which are likely to occur throughout the production run;
3. taking adequate steps to ensure that the causes of variability in product quality are brought under sufficient control to enable the required standard to be met.[4]

As a rough guide, based upon knowledge of a variety of existing organisations, it may be taken that the staff required to carry out the unmarked functions will represent between 1% and 6% of the inspection staff proper.

From this it will be seen that in the case of smaller organisations it may be found that, by careful selection and allocation, many of the necessary functions can be carried out adequately as a part-time responsibility of the existing inspection or general factory management. In such cases, however, it is recommended that some individual should be given the overall responsibility for developing that special attitude of mind — " quality mindedness ".

making a start

Most executives like to judge by results, and so before deciding to implement the actions indicated in what at first sight may appear to be a somewhat formidable Chart, they are likely to ask what benefits would accrue, and how soon.

As a start, it is recommended that one man be given the task of determining accurately the cost of parts scrapped in one month. In many cases it will be sufficient to select the output of one shop, or of a particular group of components.

Note that the operative word is " *accurately* ". Too many people are anxious to suppress the facts, or are too busy with the task of achieving programmed output, to be concerned with what gets trampled underfoot in the process.

An act of faith is next called for — the belief that a high proportion of that scrap is avoidable. In the United States avoidable scrap has become known as " gold in the mine ", and a rapid estimate of the value of the total annual scrap will show the extent to which further effort will be justified. Many American writers have given instances where the overall scrap cost has been reduced by 50% within two years or so of instituting Quality Control.

The cost of reworking defective parts may be more difficult to ascertain, but here again the effort will be worthwhile. Where facts have been determined, it has been found that rework costs are usually of the same order as the cost of scrap.

Authenticated examples of savings which have been achieved have been given by various authors :

1. *International Harvester Company.* The executive Vice-President, Mr. Levin H. Campbell, jnr., writing in 1952, stated that the savings in scrap, rework and inspection obtained by the adoption of Quality Control methods had amounted to $2,000,000 in nine months.[5]

2. *Joseph Lucas Ltd.* Mr. J. Foster Cooper described how in one year the cost of scrap, rework and inspection was reduced from £864,000 per annum to £636,000 per annum, a saving of £228,000 yearly. The cost of installing the system was £1,000.[6]

3. *Wiggins Teape Ltd.* Mr. I. F. Hendry spent £2,500 and made a net saving of £9,000 per annum.[7]

4. *American Cutlery Firm.* Mr. Frank Caplan told the author of a firm making pocket knives, with an annual turnover of $3,000,000. This firm saved $60,000 dollars per annum by a simple piece of quality engineering, which pin-pointed the stages at which trouble was occurring. Twelve of the most highly-skilled employees were employed in reworking the knives. Analysis and inspection at the right stages reduced this to one man, part-time.

5. According to Dr. J. M. Juran, the avoidable costs, or the " gold in the mine ", in American industry generally, amount to between $500 and $1,000 per operator per annum. Unpublished figures from British sources agree closely with these, viz., £100 - £300 per operator per annum.[8]

6. *Radio-tube Division.* Dr. Feigenbaum reported an increase in annual expenditure of $5,000, which resulted in a saving of $28,000 in the first year.[9]

It will probably be found that an immediate result of the interest being shown in the scrap figures will be a reduction in the total figure. It is important to realise that this will probably be due to no more than psychological effect of the knowledge of the volume of scrap which is arising, that the improvement will not be permanent, and that it will represent only part of the savings which should eventually be obtained.

In order to obtain the full value of the maximum economic reduction, it will be necessary to bring into effect the full measure of Quality Control as indicated in the Chart. It should go without saying that the next essential steps should be to determine the stages at which the scrap is arising, to determine the causes, and to take positive action to eliminate those causes permanently.

Inevitably, the initial success which will result from these efforts will confirm the value of a deeper incursion into Quality Control, and here only one word of warning is necessary. There can be too much of a good thing, and the introduction of control schemes without regard to their effectiveness, and to the potential savings, could lead to Quality Control costs exceeding the savings.

the value of the control of product quality

Having seen how to diagnose the needs of the organisation, and how to introduce the right amount of Quality Control, it now remains only to summarise the advantages which accrue. These are :

1. Reduction in cost of scrap.
2. Reduction in cost of rework of defective parts.
3. Saving in material, which may be in short supply.
4. Saving in productive labour; better utilisation of existing skilled labour.
5. Saving in inspection costs.
6. Saving in cost of dealing with customer complaints.
7. Reduction of losses due to discount on "seconds".
8. Lowering of charges to guarantee and warranty fund.
9. Fewer delays and stoppages.
10. Shortening of production cycle time, resulting in earlier deliveries, and reduction of capital locked up in work in progress.
11. Easement of difficulties and problems of production control caused by defective work.
12. Increase in customer goodwill, due to greater reliability and enhanced value of product, leading to increased business and, in the ultimate, continued survival in the face of competition.
13. Reduction of internal friction within the organisation.
14. Improvement in morale of operatives due to consciousness of a job well-done, and closer identification with the end product, leading to increased pride in their workmanship.

And not the least of these will be this last one. It is one which can have an incalculable influence upon the success of the Company which is wise enough to realise that herein lies one of the most important advantages of the proper control of product quality.

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A GUIDE TO THE CONTROL OF PRODUCT QUALITY

THE PURPOSE OF AN INDUSTRIAL ORGANISATION IS TO ACHIEVE THE REQUISITE QUALITY OF PRODUCT, AT MINIMUM COST.

CONTROL OF PRODUCT QUALITY CONSISTS OF

1

Ensuring that Adequate Specifications Exist

The overall Quality concept requires that the Requisite Quality of Product shall be carefully determined, and fully and clearly defined.

Too high a standard leads to loss of profit, too low a standard to loss of reputation and business.

This function requires a study (a) of what is needed to enable the product to fulfil its purpose; and (b) of the variability likely to arise in quantity production. Reliability and customer satisfaction will ensue only when the range of quality is such that the lowest level will always exceed that which is required of the product.

1.1 Study the needs of the product in the light of all available knowledge. Analyse records of prototype trials and of service complaints of similar products, to determine necessary level of quality.

1.2 Determine variability likely to arise in production, by observation, analysis of plant capability, rig testing, life or fatigue-testing, as appropriate.

1.3 Ensure that Acceptable Quality Level is specified clearly and unequivocally, based upon the necessary level of quality determined from 1.1.

1.4 Check Engineering Drawings, Specifications of Materials and Processes, and Quality Specifications, to ensure that together they convey to the manufacturer the A.Q.L. of 1.3.

1.5 Develop methods of inspection, non-destructive testing, and proof testing as necessary, to enable the A.Q.L. to be achieved.

2

Checking that the Specified Standards are Met.

This is the responsibility of the Inspection Department as it is commonly understood, excepting that the Inspection Audit function should ideally be carried out by an independent body.

*2.1 Prepare Inspection Plan, stipulating stages in production processes at which inspection shall be carried out, and defining method and equipment.

*2.2 Check production equipment, e g., machine tools, jigs and fixtures. Are these adequate to enable the required standards to be met?

*2.3 Control operations and processes to the standards laid down.

*2.4 Check the product against specification.

*2.5 Accept or reject the product.

*2.6 Record reasons for rejection.

*2.7 Overcheck systems and organisation of Vendors and Sub-contractors.

*2.8 Overcheck products of Vendors and Sub-contractors.

*2.9 Check ability of operators carrying out critical work, e.g., welders.

2.10 Check efficiency of inspectors.

2.11 Conduct Inspection Audit or Quality Assurance checks on finished products.

Requisite Quality is defined as that which is necessary to ensure customer satisfaction, by achieving a given standard of reliability, or fitness for purpose, in the product.

The exercise of full control of product quality will require the application of common sense, engineering, inspection, proving (e.g., by testing) and statistical methods of analysing manufacturing performance, each in greater or lesser degree according to the nature of the product, its value, its purpose, the rate and scale of its production, the personality of the organisation, and the capabilities of the personnel concerned. The Chart indicates the basic acts which must be carried out for full control to exist, but these acts will vary considerably in individual importance according to the needs of the enterprise under review.

There is no simple universal solution, nor any single ideal form of organisation. The precise title under which each of the basic acts is operated is of no significance, and it may well vary in different organisations.

The Chart should be used as a check list to ensure that no essential step has been overlooked, and as an aid to the diagnosis of the needs of the organisation. Items marked * are definitely the responsibility of Inspection and represent the great bulk of the total personnel required. See text of Paper.

3

Investigating and Eliminating Causes of Non-Conformance

Inspection and Production personnel will naturally take all possible action to eliminate causes of scrap, where these are appreciated and can be diagnosed quickly. Many problems will require a fuller investigation than can be made by those concerned with the day-to-day running of the Shop, however, and it will usually be found more expedient and effective to set up a small Quality Engineering activity with time to study these problems thoroughly.

3.1 Set up system for the rapid and accurate recording of rejection and rework.

3.2 Investigate causes of rejection and rework.

3.3 Feed back information to Production, Purchase, or Material Supplier for remedial action as indicated.

3.4 Feed back information to Design for drawing change where necessary.

3.5 Develop new methods of measurement and non-destructive testing as required for earlier identification of defective work.

4

As Cheaply as Possible

Although action along the lines already indicated will result in considerable economies, Minimum Cost for Requisite Quality can only be achieved by regarding the overall cost of Quality Assurance, i.e., Inspection, Testing, Scrap and Rework as involving a definite proportion of the total manufacturing cost which can and should be reduced.

Every facet of the activity should therefore be kept under constant surveillance and treated as a productive activity, the efficiency of which can be increased by the application of modern management techniques.

4.1 Determine total cost of quality assurance, i.e., Inspection and Quality Control labour, equipment, scrap and rework, testing.

4.2 Determine stages at which scrap arises. Redeploy inspection force to increase its effectiveness at critical points in manufacturing programme.

4.3 Do not increase inspection effort beyond the point to economical return.

4.4 Conduct tests on rejected parts to determine acceptability on a concessionary basis.

4.5 Develop processes to improve capability at no increase in cost.

4.6 Develop more efficient and automatic methods of manufacture and inspection to reduce the risk of human error.

4.7 Reduce amount of inspection by use of Control Charts and Sampling Schemes, where possible.

4.8 Apply Work Study to Inspection operations.

recent and current developments in

ELECTRIC ARC WELDING

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A Paper presented to the

Newcastle upon Tyne Section

of The Institution

of Production Engineers

on 21st September, 1959

IN opening a discussion on recent and current developments in electric arc welding, one is confronted with many new electrodes and processes, especially in the semi-automatic and fully automatic welding fields.

The history of the development of welding has been reviewed many times by others and many production engineers will be familiar with the use of manual welding, which has now become just another tool in the armoury of a modern engineering works. Even so, the development of manual electrodes is very far from static.

iron powder type electrodes

One of the most important advances in the past two years or so, and one of particular interest to production engineers, is the increasing use of electrodes of the iron powder type.

More and more, the emphasis is on increased speeds of welding and in contrast to conventional manual electrodes, those containing iron powder in significant quantities increase the speeds of welding by up to 100%.

Most conventional electrodes have coverings of the rutile type, i.e., containing oxides of titanium. This is in order to obtain easy flowing of the molten slag, easy slag detachability, smooth arc characteristics and good operational properties for horizontal-vertical fillet welding. However, the physical properties of such electrodes suffer at high currents. The particular development concerned is the addition of significant quantities of iron powder to the covering, permitting a much higher current carrying capacity and a greater metal recovery rate, i.e., percentage of deposit to core wire. In iron powder electrodes, this can reach 140% according to type and circumstances. In order to use the higher current capacity of iron powder electrode,

TABLE I

TIME AND COST OF DEPOSITION PER CUBIC INCH OF BUTT WELD

Type of Electrode	*Amps*	*Quantity of Electrodes used (inc. 2" stubs)*	*Time to Deposit*	*Cost of Electrodes*	*Labour Cost*	*Overhead Cost*	*Gross Cost*
Iron powder	300	2.68 ft.	2.50 min.	7.71d.	7.50d.	11.25d.	26.46d.
Conventional Class 2	240	3.60 ft.	4.00 min.	5.18d.	12.00d.	18.00d.	35.18d.

Duty cycle — 33⅓
Labour — 5/- per hour
Overheads — 150% on labour

it is important that the weld metal deposited shall be low in hydrogen. This is not always the case with these electrodes if of the rutile base type and a current development is, in fact, that of an iron powder electrode giving mechanical properties analogous to low hydrogen types.

Broadly speaking, the advantages over the conventional types are:

1. higher deposition rate, almost double;
2. a weld of greater length for a given size;
3. high radiographic standard;
4. good mechanical properties;
5. in the case of certain types, the use of the electrode in all positions;
6. good weld profile;
7. easy slag detachability.

The net results of all these factors is a saving in gross cost per foot of weld in the order of 35% - 50%, according to circumstances, types of joint, and the particular electrode applicable to the job.

The details given in Tables I and II indicate the costs of the iron powder types in the case of butt welds and fillet welds.

Developments in manual welding are not, however, confined to the heavily coated iron powder electrodes. Improvements in metallurgical aspects have increased the welding speeds of some conventional types. The latest, used for flat and horizontal-vertical fillet welding, give a mitre or slightly concave profile. Furthermore, a size larger electrode than usual can be used to give increased length of fillet weld.

semi-automatic processes

Semi-automatic welding, where the wire or electrode is fed by an electrically driven wire feed unit through a hand-held pistol, is now being rapidly developed. There are a number of processes available for mild steel, including the use of bare wire with a gas shield, a tubular electrode with a CO_2 shield and the use of a bare wire with a magnetic flux carried in the CO_2 gas stream.

TABLE II

TIME AND COST OF DEPOSITION PER FOOT OF 5/16 in. HORIZONTAL-VERTICAL FILLET WELD

Type of Electrode	*Amps*	*Quantity of Electrodes used (inc. 2" stubs)*	*Time to Deposit*	*Cost of Electrodes*	*Labour Cost*	*Overhead Cost*	*Gross Cost*
Iron powder	300	1.12 ft.	1.17 min.	3.23d.	3.51d.	5.26d.	12.00d.
Conventional Class 2	240	1.88 ft.	2.33 min.	2.70d.	6.99d	10.48d.	20.17d.

Duty cycle — 33⅓
Labour — 5/- per hour
Overheads — 150% on labour

Fig. 1. Operator using semi-automatic welder feeding thin aluminium or steel wire under a shield of argon or argon/oxygen gas.

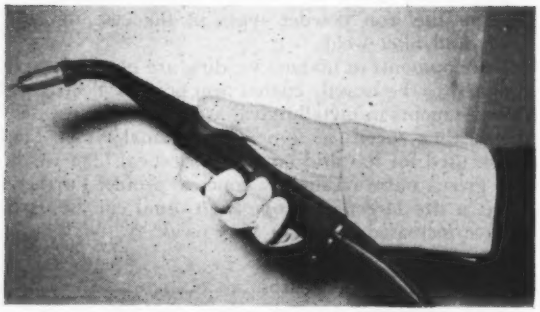

Fig. 2. Hand torch for feeding 0.030 in. and 0.02 in. dia. wire for the welding of thin gauge material.

Fig. 3. Sheet metal pressing welded to tubular front axle.

Fig. 4. Pressed sections in thin sheet welded together to form vehicle front axle.

All these alternatives give faster metal deposition rates than manual electrodes, even if iron powder electrodes are considered. In all cases, however, the cost for the consumables (wire, gas and flux, if any) in the continuous form, is higher than the cost for the equivalent electrodes.

Thus the adoption of a semi-automatic process for any particular work depends on the balance of increased consumable cost against a decrease in labour cost. The capital of a semi-automatic installation will be in the order of £1,000 more for each operator than for manual welding equipment.

Nevertheless, in many cases the reduced labour cost and increased productivity given by semi-automatic welding much more than offset the higher cost of consumables and plant. Fig. 1 shows a typical semi-automatic machine.

The use of a bare wire with CO_2 welding has now also been developed for welding thin gauge materials, and the torch shown in Fig. 2 is used with .020 in. and 1/32 in. wire for welding sheet metal components such as those shown in Figs. 3 and 4.

As an alternative, the equipment shown in Fig. 5 can be used. Here the electrode wire is wound on a small spool carried on the gun itself, and although this makes the gun somewhat heavier it can be easily used over a wide area without having to move heavy equipment. In addition, this equipment can also be used to feed small diameter aluminium wires so that aluminium sheet down to 16 SWG can also be welded with this equipment.

fully automatic welding

This review of developments in the sphere of manual and semi-automatic welding brings the subject of production welding to the use of fully automatic processes.

The use of automatic welding as such cannot be considered as new. The four or five years preceding the last War saw the earlier installations in the United Kingdom. The War years, of course, forced upon many industries the need to adopt automatic welding which they followed in post-War years.

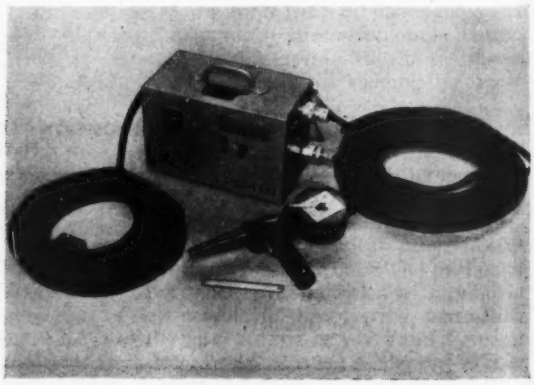

Fig. 5. Semi-automatic welding machine for feeding very thin aluminium and steel welding wires.

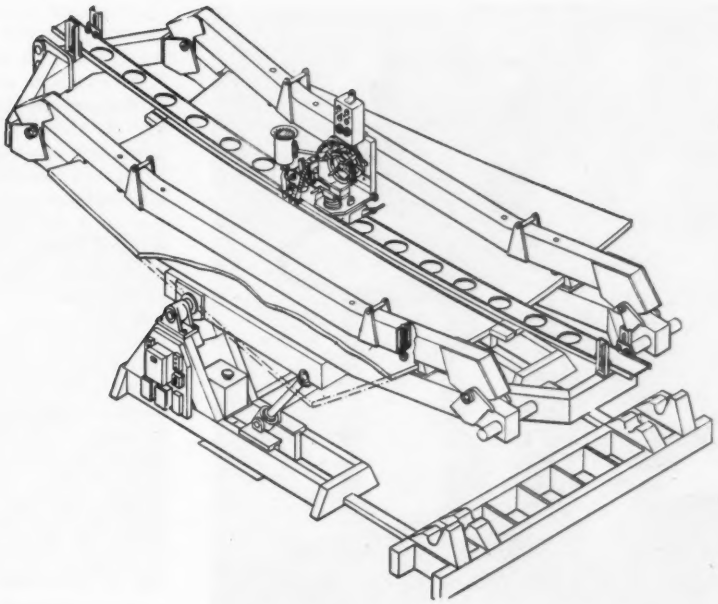

Fig. 6. Layout of installation for fabricating sections of the sphere.

The more recent developments probably will be in the use of automatic welding in the construction of nuclear power stations, particularly in the fabrication of the spheres and also the heat exchangers. In both cases, the principal interest lies in the elaboration of the handling equipment required for positioning the weldment for downhand welding.

An interesting application, illustrated in Fig. 6, is a tilting manipulator and handling frame for fabricating sections of heavy plate forming the sphere.

The illustration shows an artist's impression of the jigging adopted. The two curved plates are held in the frame mounted on a tilting table. A separate track, swept to the curvature of the plates, carries a portable welding machine. Synchronisation of the welding speed with the angle of tilt allows the operator to keep the welding in the downhand position.

A further feature is the provision of pegs on the handling frame which engage with pivots on the base frame. The use of the pivots is illustrated by Fig. 7, which shows the welded curved panel being lifted for positioning and eventual removal.

A close view of the welding machine used on this jig is shown in Fig. 8. Two welding heads are employed, each independently feeding a welding wire into the same weld pool. The welding currents and arc voltages used on the heads are independent of one another and can therefore be adjusted to provide the best conditions. The system is known as

Fig. 7. Special jig for fabricating sections of the spheres in nuclear power stations.

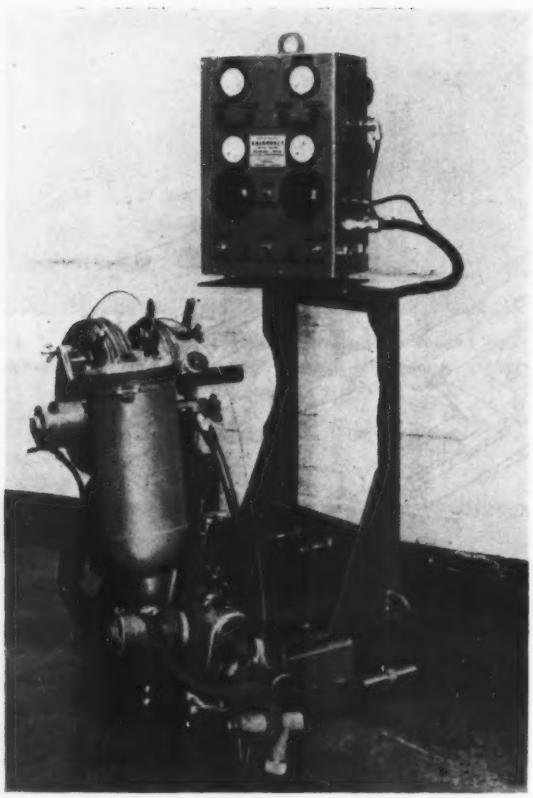

Fig. 8. Double-headed self-propelled welding machine.

multi-power welding and it has the great advantage of increasing the welding speed up to twice that permissible with a single wire.

An example of welding applied to the fabrication of the shells of large heat exchangers is illustrated in Fig. 9. Here we have developments of particularly large, self-propelled high lift booms used to support automatic welding heads for internal and external longitudinal and circumferential seams. An idea of the size may be gauged from the fact that the strakes on the roller beds are 20 ft. in diameter and are $2\frac{1}{4}$ in. thick. The boom — which is one of the largest of this type in the world — has a vertical lift of 30 ft., and as illustrated, points in a fixed direction and is used mainly for the external seams. However, this boom has a companion of the same general size, reach and vertical lift, except that the boom and vertical column are mounted on a turntable swivelling through practically a full circle. Both of these booms are on carriages which travel at either welding speed or fast positioning speed. An impression of the size of the boom and also the job itself can be obtained from Fig. 10.

use of electrical equipment

An interesting feature of the installation is the electrical equipment on the booms and roller beds. Each bed carries its own rotation and traverse motors fed from its own electronic control cabinet. Each bed therefore is a self-contained, independently operational unit but, more particularly, any one bed may be the master controlling any others that work in train with it. Alternatively, either of the booms may be the master of a train comprising any number of beds.

The fabrication of large pressure vessels of such thicknesses is somewhat specialised and developments are taking place in other fields, in shipbuilding, for example.

The most interesting development is the increasing employment of the open arc automatic process for the fillet welding of bulkhead stiffeners by using continuous flux covered electrodes in combination with a shield of carbon dioxide gas. The process particularly lends itself to fillet welding although large gantries, as shown in Fig. 11, can with adaptation be used for butt welding. Fig. 12 shows a gantry in use in the prefabrication shops at a shipyard.

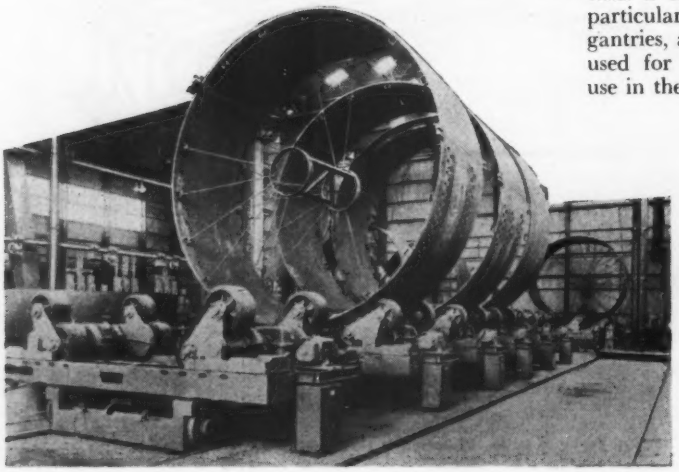

Fig. 9. View of heat exchanger shells on roller beds and showing high lift boom.

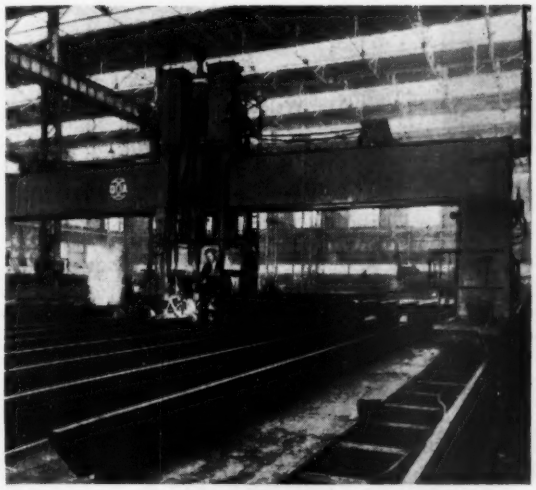

Fig. 12. Gantry in use in shipyard welding bulkhead stiffeners.

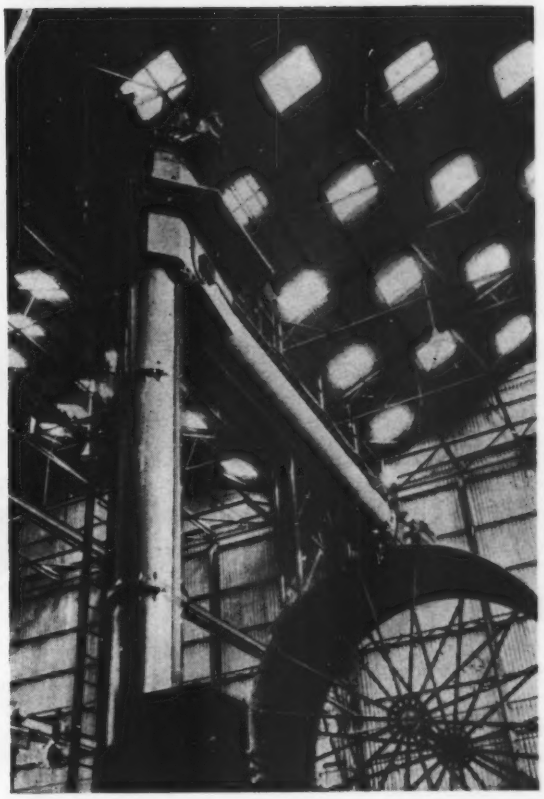

Fig. 10. View of large high-lift boom making longitudinal welds.

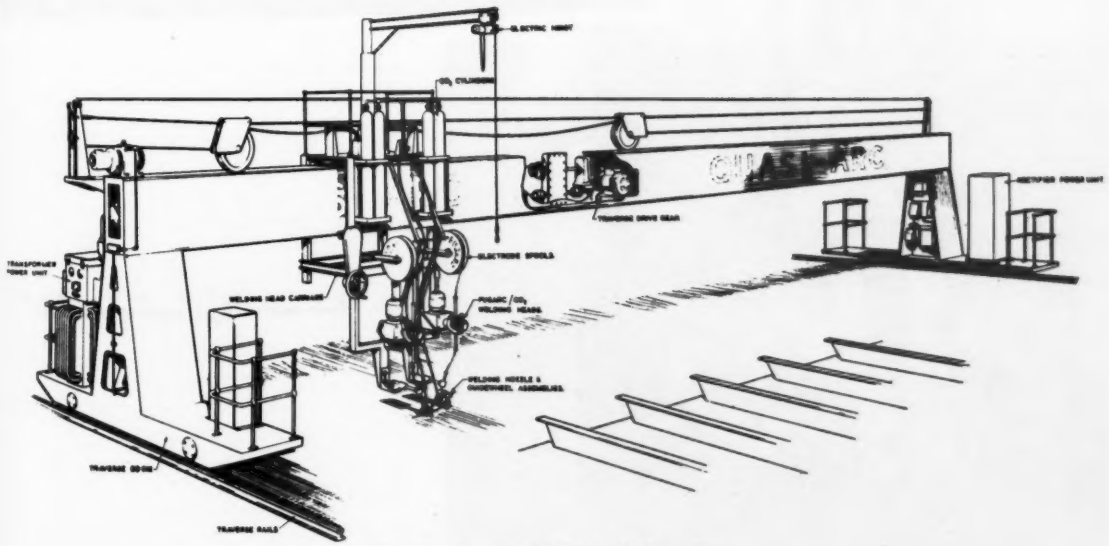

Fig. 11. Layout of fillet welding gantry.

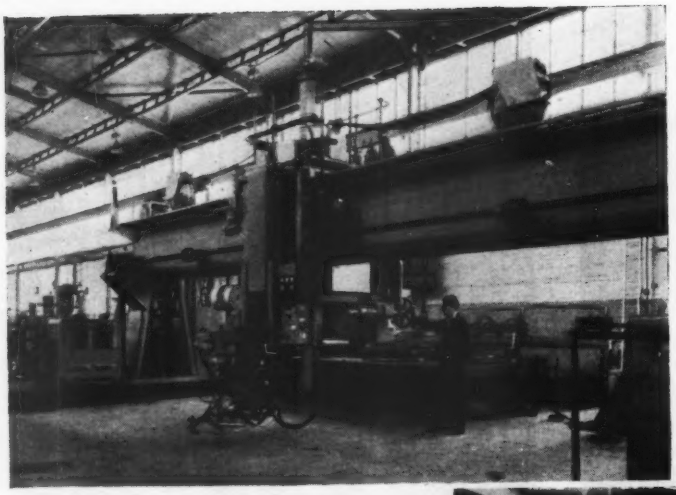

Fig. 13. Welding gantry under construction.

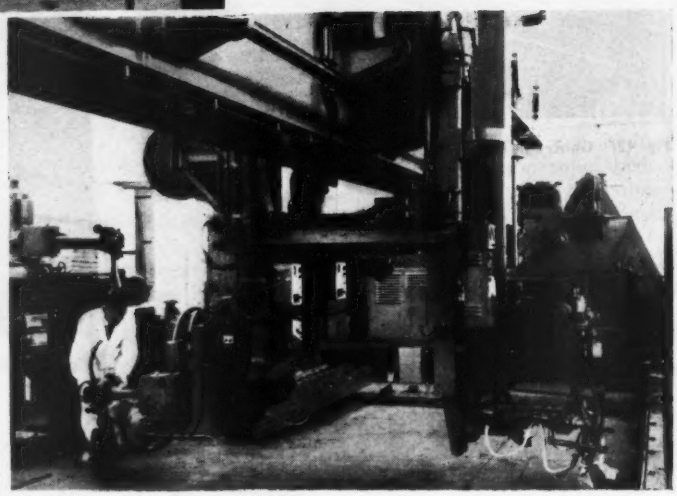

Fig. 14 (right). Close-up of welding heads on a gantry.

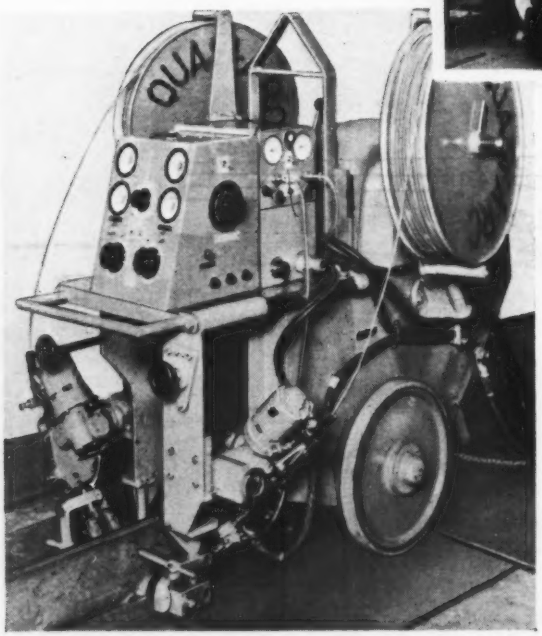

Fig. 15 (left). Twin-headed fillet welding machine.

A gantry under construction is shown in Fig. 13. In this case the travelling carriage is equipped with welding heads for making fillet welds on aluminium stiffeners using ARGON as a shielding gas. The opposite side of the carriage is equipped with welding heads for feeding continuous covered electrodes under a shielding of CO_2 gas, and is shown in Fig. 14. The gantry can, therefore, be used with increased versatility consequent on the adoption of more aluminium in ship construction.

In some yards, the use of a gantry is prohibited by limitations of space.

A recent development of a smaller machine using a gas-shielded arc is the self-propelled twin-fillet welder as illustrated in Fig. 15.

This machine is entirely self-guiding and puts down two $\frac{5}{16}$ in. leg length fillet welds in one pass simultaneously at a speed of about 20 in. per minute. Machines of this type, already in service, are producing 700 - 800 linear feet of fillet welds per day. This is in contrast to 150 feet per day from a manual operator.

The application of this machine is not confined to the shipyards. In an adapted form, it can be used for welding the web and fianges of I-section beams up to 36 in. high and 18 in. across the flange.

an interesting application

An interesting application of automatic open-arc shielding gas welding combined with special jigging is that of a 60 ton press and backing bar, shown in Fig. 16.

This machine was developed in order to butt weld large plates together to form the laminations of a large magnet. In order to counteract distortion and to ensure that the plates were perfectly flat after welding, the copper backing bar was cambered along its length — about $\frac{3}{16}$ in. in 6 ft. Those plates which were $\frac{1}{4}$ in. thick were welded from the upper side only, which necessitated the copper backing in order

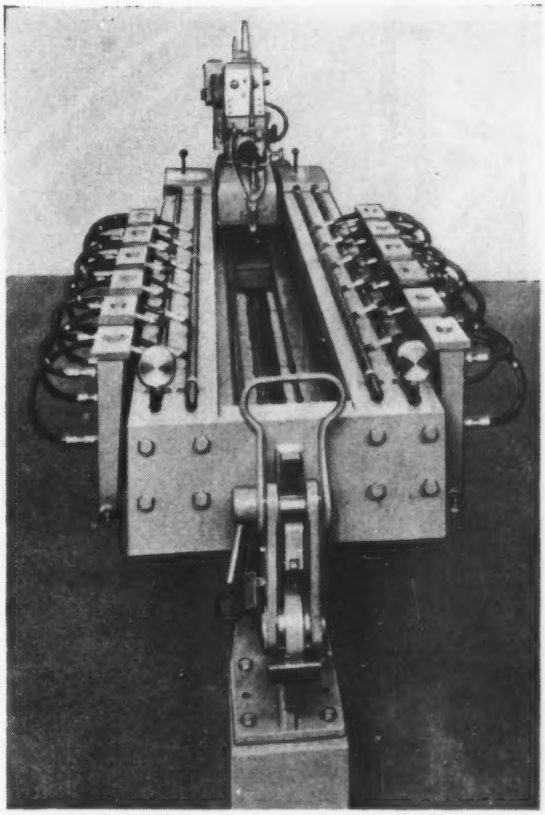

Fig. 16. 60 ton backing bar press.

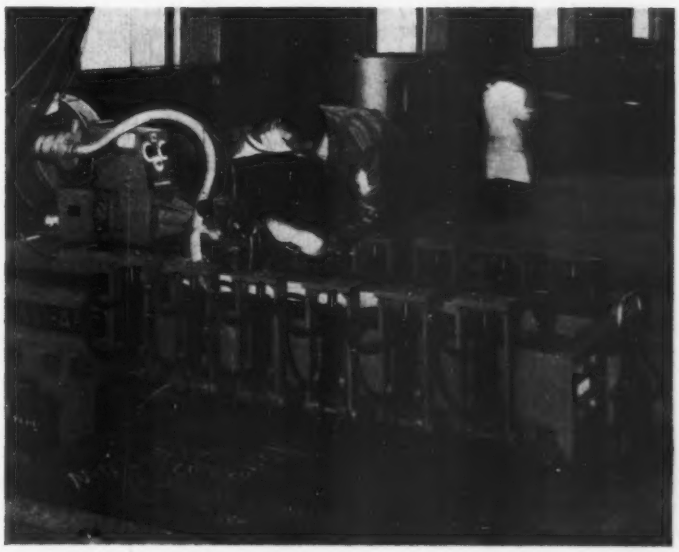

Fig. 17. 60 ton backing bar press in operation.

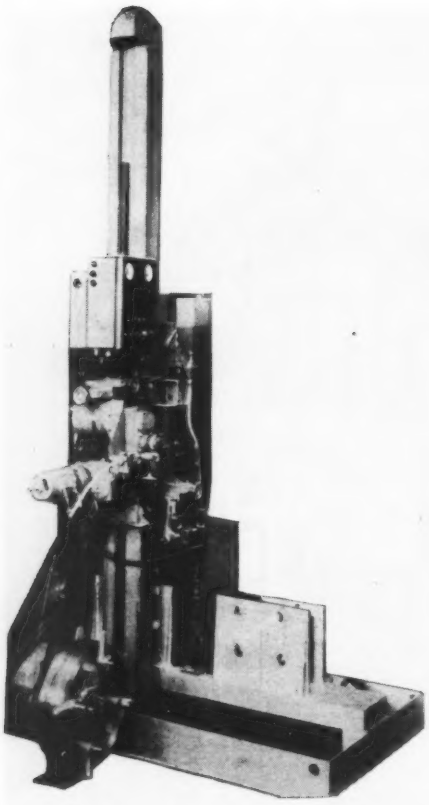

Fig. 18. Vertical welding machine.

to obtain 100% penetration. Other plates, of ½ in. thickness, were welded on both sides — i.e., two-pass welding.

Fig. 17 shows the machine in operation. The total clamping pressure was 60 tons, obtained from 12 independently operating hydraulic rams.

About 18 months ago, the first British-made vertical welding machine was introduced. This machine uses the electric-slag principle, in which a bath of molten steel and slag casts a weld between the edges of two plates supported in the vertical plane. The machine is illustrated in Fig. 18.

a great advantage

Although the electric-slag process is not new — having been used for some years in Russia — it is nevertheless a recent development in Britain. To what extent this vertical welding system may be applied to British practice remains to be ascertained and studied. It clearly has very real possibilities in the fabrication of heavy sections. It has the great advantage that plate edge preparation—other than straight flame cuts — is unnecessary and that the fabrication need not be positioned for downhand welding. What is to be considered and studied are the metallurgical features of what is virtually a "cast" weld.

Developments have taken place in jigging for inert gas welding processes. A typical example, shown in Fig. 19, is that of a copper backing bar jig for joining stainless steel strip in a rolling mill. Fig. 20 shows a closer view of the two welding heads and the finger-type clamps.

Improvements in the clamping of the two edges have now made it possible to fuse the edge of stainless steel plate up to 0.20 in. thick. Hitherto, this thickness was considered beyond the scope of tungsten electrode welding where the fusion must be made from one side of the joint. The machine actually forms part of the production line of the mill and is

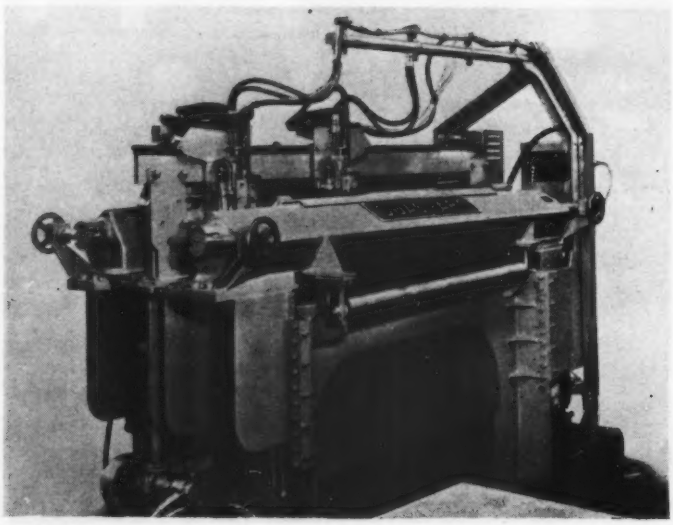

Fig. 19. Backing bar jig for stainless steel strip.

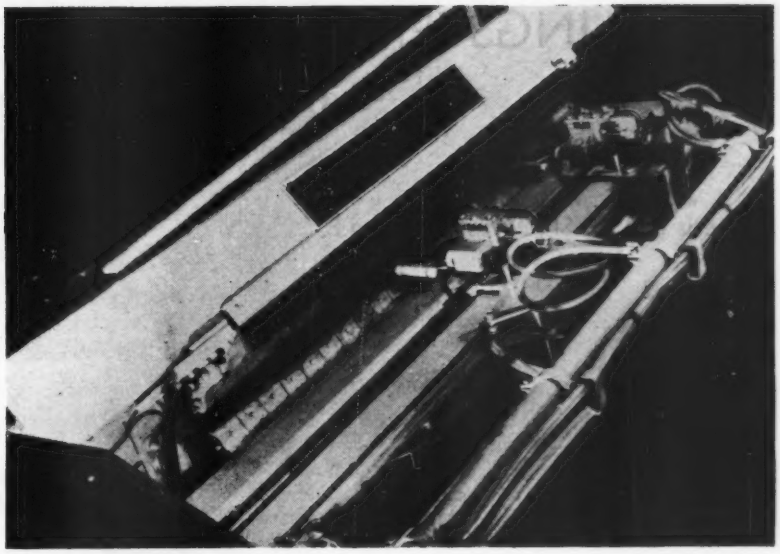

Fig. 20. Backing bar jig for stainless steel strip showing welding heads and finger-type clamps.

designed so that the strip may feed through it after the edges have been welded together.

One of the most important applications of automatic welding is that of reclaiming or the hard surfacing of worn parts. This is not, of course, a recent application and in one particular field — namely that of worn tractor parts — neither is the re-surfacing of worn track links by automatic welding methods.

What is more recent is the development of special twin-headed machines so that both sets of links of a worn track may be re-surfaced simultaneously. A machine of this type is shown in Fig. 21.

Both welding heads are carried on a common carriage travelling at welding speeds above the track. The weld at each link is initiated by a train of H.F. sparks as heretofore, but as a recent development, the cams used for controlling the sequence of operations are substituted by a photo-cell system in conjunction with simple plastic templates.

As a further feature, the welding heads are designed to use a number of alternative automatic processes to met any specified requirements. The heads can be used for submerged arc welding, i.e., a bare wire combined with a fusible granular powder as flux or alternatively a combined method may be used, namely, that of a continuous covered electrode with the weld deposit buried beneath a covering of granulated powder. A further alternative is the use of a continuous covered electrode in conjunction with a shielding of carbon dioxide gas.

Each process has its particular merits, that of the straight submerged arc giving a particularly smooth surface as deposited; the other two processes having the advantage of a wider range of deposit hardnesses. From the manufacturing point of view, the covered electrode is a more flexible medium for obtaining desired hardness than is a cast and drawn bare wire.

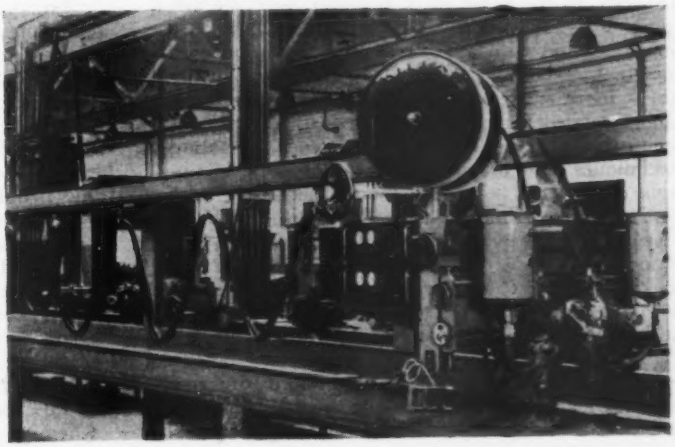

Fig. 21. Twin-headed track link reclamation machine.

THE TUNGSTEN CARBIDE ROTARY CUTTER

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THE term "rotary cutter", applicable quite legitimately to a host of different types of engineering tools, is a broad indication rather than a distinct classification and to discourse freely upon the subject without some visual identification is to invite ambiguity and general confusion. The examples in Fig. 1 indicate some typical shapes of the tool concerned.

The research and manufacturing problems associated with such tools, even when produced in the conventional high-carbon and the high-speed steels, are quite substantial — yet the finished products are of such relatively low cost that their expendability rate is accepted throughout industry with no great concern. In the latter years, however, with the introduction of new materials and alloys difficult to machine, and with an increased appreciation of the inherent versatility of the rotary cutter, the demand for a more efficient tool with greater cutting power and extended life has been phased, fortunately, with concurrent developments in powder metallurgy techniques, and manufacture of the cutter in tungsten carbide has become well-established.

Current experiments in the sintering of oxides and borides of elements other than tungsten will, undoubtedly, lead ultimately to the use of cutting media with yet greater properties than tungsten carbide. But limited trials with tools so produced, although demonstrating varying degrees of efficiency at extremely high feeds and speeds, have failed as yet to prove any positive overall superiority and many adverse features have yet to be corrected before such tools can be accepted into industry with the enthusiasm that tungsten carbide appears to have justified.

structural forms of the rotary cutter

The tungsten carbide rotary cutter is produced, usually, in two structurally different forms. In Fig. 2 the tool is shown as a "solid" carbide, an unacceptable term, technically, but nevertheless indicative of the intended meaning that the head and the shank are formed integrally in tungsten carbide. The alternative, generally more popular by virtue of its tougher shank, is sketched in Fig. 3. This tool has a shank of conventional steel bonded securely to the tungsten carbide head by means of a brazed joint.

To appreciate the reasons for the difference in construction, however, and to understand the necessity for issuing to a customer some rather bewildering recommendations on the correct use of the tools, a short resumé of the production technique of tungsten carbide forms, and results of various tests made, will be helpful.

the production of tungsten carbide forms

The manufacture of tungsten carbide, pioneered by the Osram Lamp Company in Germany and later developed by Krupps, began about 1926. Its then proprietary name of "WIDIA", derived from the simple contraction of the two German words "Wie Diamant" (like diamond) soon became the criterion of high quality tungsten carbide throughout the world. The potential of this so-called "man-made" metal was very quickly appreciated in Britain, where production commenced in the early 1930's.

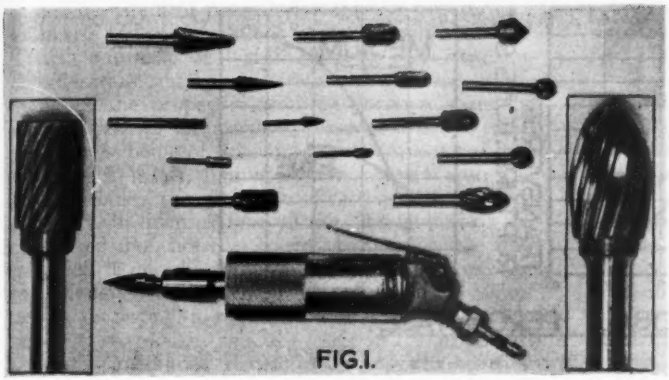


FIG.I.

Fig. 2.

Its development issued from the knowledge that the high carbon steels, then the principal material used in the manufacture of cutting tools, fail rapidly in hardness values at temperatures in the region of 270°C. At the beginning of the 20th century attempts to improve the quality of this steel resulted in the addition of other elements, principally tungsten, chromium and vanadium, into the composition. With these additives hardness was retained quite effectively at temperatures in excess of 500°C and thus the high-speed steel range was initiated into industry.

the basic method

Microscopic examination of this steel reveals the structure to be permeated with an even distribution of the carbides of iron and of tungsten, the intense hardness of the latter being noted with particular interest during the development period. Enthusiastic attempts to produce cutting tools in tungsten carbide alone, however, resulted in complete failure due principally to its extremely high melting-point (approximately 3,000°C) and to the absolute brittleness of the final structure. Variations of technique nevertheless produced a method which, basically, is still universally practised: whereby tungstic oxide is treated at high temperatures in a reducing atmosphere of hydrogen gas, the oxygen from the tungstic oxide combining with the hydrogen to form water vapour, and producing an extremely dense mass of tungsten powder. Rigid control of this process — oxide quality, gas flow, cycle times and so on — determines, to a great degree, the purity and grain size of the tungsten; two cardinal factors upon which the efficiency of the completed tool depends.

The tungsten powder is then mixed with carbon and again subjected to high temperatures, approximately 1,500°C, in a reducing atmosphere, the carbon combining with the tungsten to create tungsten carbides.

Cobalt oxide, processed in a manner similar to that of tungstic oxide reduction, produces a powder which, with the tungsten carbide, is ball-milled for considerable periods, usually several days, to ensure the thorough and intimate intermixing of the two powders — the balls and the lining of the mills being made also of tungsten carbide to assist in the maintenance of purity standards and, naturally, to resist the extreme wear that would be inevitable on any other material.

Additions of the carbides of other elements such as titanium, tantalum, chromium and molybdenum, for instance, are effected at this stage if necessary to the particular application of the finished product, together with a quantity of paraffin wax, the latter to promote a degree of temporary cohesion of the particles. The resultant mixture is then pressed into moulds under pressure of at least 10 lb. sq. in. due allowance being made for volumetric shrinkage of between 18% and 30% which occurs in the final operation — that of "sintering".

The sintering furnace, provided with ancillary equipment for the close control of temperatures, usually takes one of two forms — hydrogen reducing or vacuum. The moulded units are placed in a preheating zone to ensure expulsion of the paraffin wax and are then moved into the maximum heat zone where the soft and friable pieces are sintered into intensely hard tungsten carbide units, the cobalt element liquefying in the process to form a strong matrix, or cement, for the tungsten carbide particles. The finished units retain their hardness at very high temperatures and cannot be annealed. Machining can be executed only by silicon carbide grinding, diamond lapping, electro-erosion or ultrasonic processes, but where such machining is likely to be extensive, the

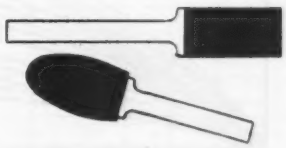


Fig. 3.

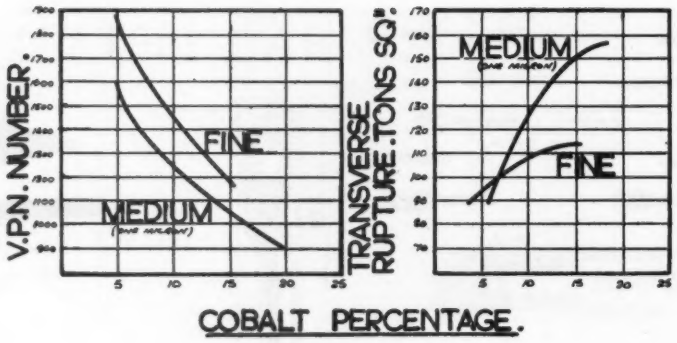


Fig. 4.

Fig. 5.

method known as " pre-sintering " is usually adopted. This method involves the arresting of the sintering operation at about 900°C when the components are sufficiently soft to permit, after cooling, normal machining operations, after which they are returned to the furnace for completion of the sintering cycle, from which they emerge with the characteristic hardness conferred by the normal " straight through " sintering.

Many variations of the foregoing method are practised, but the process roughly outlined is generally satisfactory, and common to all the known techniques. Although dimensional tolerances on regular shaped units can be held to very close limits, deformations occurring in the more unusual shapes, of which the rotary cutter is typical, must be corrected by post-sinter machining.

grade selection and testing

The rotary cutter, by virtue of its particular and intermittent cutting action, develops a " chipping " effect and the additions of the carbides of titanium and/or tantalum into its basic composition would appear to be superfluous, even detracting from the properties required. The purpose of such additives is to reduce the known affinity existing between the tungsten carbide and steel when the temperature at the cutting edges reaches the critical point at which " cratering ", through partial fusion, occurs on the tungsten carbide surface — a circumstance more applicable to the lathe tool rather than to the intermittently cutting rotary tool. Nevertheless, certain types of rotary cutter, due to specific applications for which they are intended, justify the inclusion of these extra carbides as a precaution against rapid breakdown through excessive brittleness of the structure — both tantalum and titanium improving the toughness of the structure although detracting from the overall hardness of the tool.

The finished " blanks " are classified therefore as either " compound " or " straight " carbides and prove to be extremely satisfactory when, as finished tools, they are used in accordance with the manufacturers' recommendations, the issuing of which is somewhat committal and which produces the necessity for the intensive research and proving of all processes involved in the making of the tools.

Tests on both the " straight " and " compound " carbides rapidly produce evidence of their characteristics — intense hardness (and its retention at very elevated temperatures) and good rupturing strength being of vital importance. Figs. 4 and 5 typify the results of some of the extremely protracted tests necessary in the early stages of rotary cutter produc-

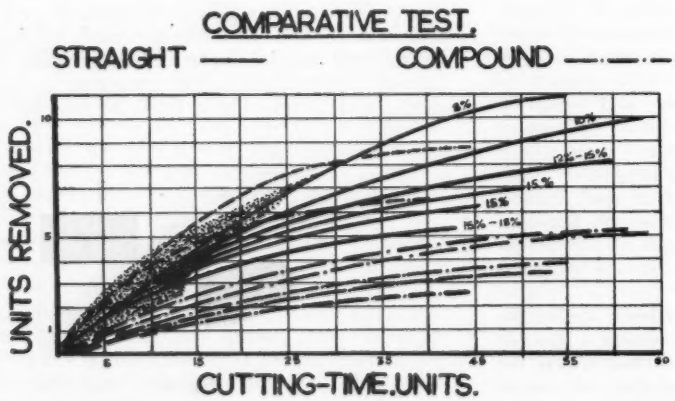


Fig. 6.

tion. The extent of permutation through variation of grain size and cobalt content alone is readily apparent, "particle-form", or "grain-shape", also requiring consideration, and much careful thought and assessments of the properties required becomes necessary so as to restrict the range to reasonable proportions.

Hardness being of prior importance, it is noted that the highest V.P.N. figures are synonymous with fine grain carbides, the grain size of carbides being rated, generally, in microns/cross-section. Toughness of the completed tool, however, owing to the versatile uses to which it may be subjected, and distinct from the tools designed for a particular range of applications, proves, on testing, to require almost as much consideration as hardness, and the proportion of cobalt cementing medium is decided from repetitive cutting tests with tools containing various but known quantities. In the case of compound carbides, of course, the proportions of compounding elements must also be known and religiously "logged". Fig. 6 indicates the results of some comparative testing from which it is reasonable to accept the apparent superiority of a fine grain "straight" carbide containing some 8% cobalt. Closer examination, unfortunately, reveals an extensive critical period, denoted by over-shade, during which the cutting edges tend to break-down through instability due to excessive brittleness of the carbide structure; thus it becomes an involved problem to decide upon the structure most suitable for any given range of tools.

High V.P.N. figures, however, are required to be reasonably stable even at high temperatures such as may occur when the tool is cutting hardened die-steels; the rapid work-hardening Nimonics; the ceramics and so on. Further tests are necessary to assess the reaction of the hardness characteristics to the application of heat. There are several ways of accomplishing this but one of the most efficient methods involves the mounting of sample units, so formed as to receive a thermocouple probe of the thermistor type, on to a specially adapted hardness-tester, high frequency heating equipment being used to induce the heat into the unit. With the heating being electronically controlled, and triggered by variations of readings on the associated galvanometer or pyrometer to hold it steady as the indentations are made, very reliable and consistent results appear satisfactorily to substantiate the figures expected. Fig. 7 indicates the results of some such tests.

the shank

"solid" carbide tools

So far, high-hardness characteristics, commensurate with an essential degree of toughness, have been concerned primarily with the generation of good cutting qualities, an aim which, in regard to the "solid" carbide cutter, limits the strength of the shank and, therefore, jeopardises the life of the tool as a whole.

Ideally, were it possible to sinter the head in a high-hardness grade of tungsten carbide with the shank in a grade of maximum strength, the major part of the whole problem would be resolved. Although much experimental work has been carried out with this in mind, and some success achieved by "cobalt fusion" of identical grades with carbides of different structures, loss of homogeneity at the intimate fusing area precludes the practising of this technique, leaving the sole alternative of ensuring that the shank cross-section area is of sufficient magnitude to support the extreme loading that may be applied at the head of the cutter.

From Fig. 5 it is shown that a fine-grain carbide is endowed with a transverse rupture strength of something like 100 tons/sq. in. The Izod figure for this grade, however, is relatively low at approximately 0.7 ft. lb. and thus, where the unit is reduced in diameter to blend into the shank, the quality of the tool's resistance to shock loading becomes entirely dependent upon the greatly diminished properties of the reduced cross-sectional area. Efficient design, therefore, based on functional evidence, is naturally of vital importance and must be centred, dimensionally, upon the proved relationship between the head shapes and sizes, and the shank cross-sectional areas.

Collation of the necessary data, from which is extracted the information pertinent to design, derives from exhaustive testing of finished cutters on special equipment capable of reproducing most of the adverse conditions and treatments to which the tool may be subjected in the workshop. Apart from producing means for computing the stock-removal rates and incidental details for the recommending of feeds

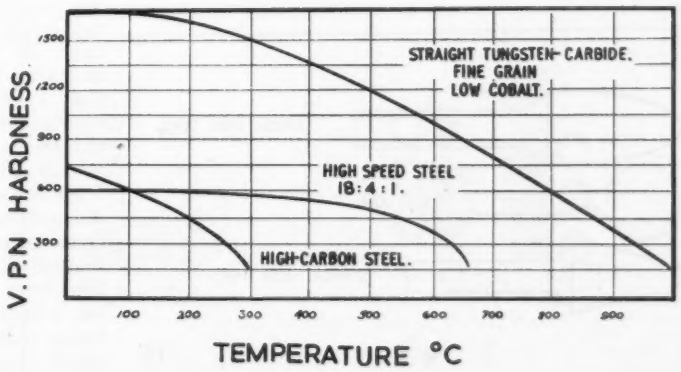
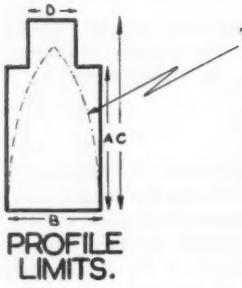


Fig. 7.



HEAD DIMENSIONS.

	SHANK DIA.				
	1/8" & 3mm.	3/16" &	1/4" & 6mm.	5/16" & 8mm.	3/8" & 10mm.
A	3/8"	1/2"	3/4"	1"	1¼"
B	1/4"	3/8"	1/2"	5/8"	3/4"
C	1/2"	7/16"	1"	1¼"	1½"
D	1/8"	5/16"	1/4"	5/16"	3/8"

Fig. 8.

and speeds for various applications, such equipment enables the behaviour of the shank, under closely controlled degrees of eccentricity, to be investigated with extreme thoroughness. Microscope and stroboscope apparatus, together with means of inducing known eccentricities into the cutting action, are prominent features of this test gear, and recent developments in the field of capacitance metering are exploited in the measuring, dynamically, of the frequency and amplitude of the forced displacements of the running cutter from its true centre.

Such investigations, again in view of the extreme permutability of all the factors involved, are somewhat protracted. But in all cases few doubts remain that, even when designed and manufactured to rigid specifications, ultimate efficiency of the tool lies very much with the individual intelligence of operators in colletting the cutter tightly and as closely to the head as is reasonably possible and in exercising some care to eliminate any cause of eccentricity which, dependent upon the r.p.m. of the cutter and the amount of displacement from true centre, becomes capable of producing impact shocks of sufficient intensity progressively to break-down the cutting edges and, ultimately, to fracture the shank.

To conform with universally adopted colletting arrangements, the shank diameters range from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. with, as near as possible, metric equivalents, and, unless special applications demand exceptions, relationships between the head dimensions and the shank diameter tend closely to follow the general indications shown in Fig. 8.

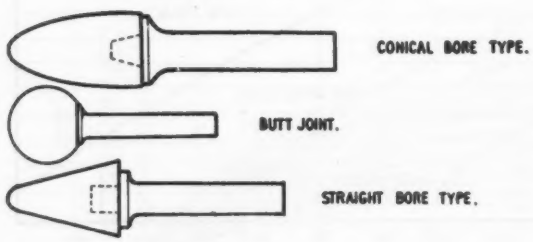


Fig. 9.

conventional steel

Throughout the "solid" carbide range, it is noted that if the head itself comprises X cubic units of tungsten carbide, the shank may represent an addition, relative to the head dimensions, of anything between $X/3$ and $4X$ units. The devising of an alternative shanking method, therefore, apart from aiming to improve upon the strength characteristics of the carbide shank, issues from the incidental competitive requirements to diminsh costs. Assuming that post-sinter machining of the "solid" type may incur, as it invariably does, some 20% - 40% of the total cost of the blank, then sintering of the head alone, with the consequent closer control over sintering deformations, eliminates the necessity for any form-truing operation. Thus, provided the shanking operation can be effected at a low cost relative to the $X/3$ and $4X$ factors, the overall saving can be considerable.

The cardinal requirements, of course, of any shanking operation must be to ensure that the ultimate efficiency of the completed tool is at least equal to that of the "solid", and that the shank is capable of withstanding all the test loads and impact shocks it is likely to encounter.

Whatever method is devised, initial consideration must be given to modifications to the head and in Fig. 9 are shown some variations deemed necessary. The basis for such modifications arises from the requirement that, although it is intended that the shank shall be brazed face to face with the head, there are particular instances were a spigot type of mounting functions as a safeguard should the brazed joint fail during a machining operation. A head parting from its shank when running at speeds in the 20,000 r.p.m. - 40,000 r.p.m. region can be, to say the least, somewhat disconcerting. A spigot also functions to a limited extent as a key which, accepting some of the torsional stresses during cutting, contributes to overall efficiency of the brazed joint.

Head cavities or bores, however, must be relative, dimensionally, to head sizes. Where, for instance, a recess of certain diameter is envisaged, it has to be realised that after a substantial number of "re-cuts", (the term used for the resharpening service) there lies a distinct probability of the tooth-root diameter being reduced to a stage where "break-through" occurs. The tool is then scrapped.

selection of steel

Good sintering can ensure that the head "blanks" are produced to dimensional tolerances within limits of 0.003 in. per $\frac{1}{2}$ in. of diameter and within 0.006 in. per inch of length. Consequently, with the elimination of post-sinter correction operations, one of the final problems associated with the completion of the tool is the selection of suitable shanking steels. Such steels have to be easy to machine in view of the necessity to produce shanks fairly rapidly and, therefore, economically; they must have good tensile strength and be consistent in quality.

Tests with cutters to which have been fitted shanks made from various steels show that the properties producing satisfactory results are as indicated in Fig. 10.

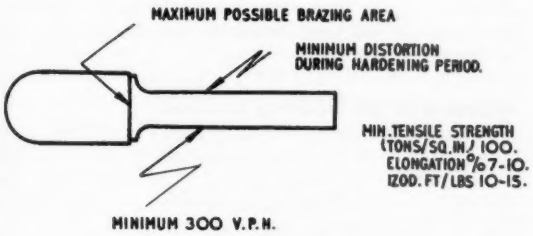

MAXIMUM POSSIBLE BRAZING AREA
MINIMUM DISTORTION DURING HARDENING PERIOD.
MIN. TENSILE STRENGTH (TONS/SQ. IN.) 100.
ELONGATION % 7-10.
IZOD. FT/LBS 10-15.
MINIMUM 300 V.P.N.

Fig. 10.

Such properties are inherent in a wide range of steels as used in the manufacture of combustion-engine valves, chisels and high-speed cutting tools; some steels of the Nimonic group are also particularly suitable.

bonding of the shank to the head

Although the preceding details relating to the steel-shank tool would appear to suggest a finished product superior to the "solid" carbide counterpart, the true result is almost entirely dependent upon the properties and efficiency of the joint between the shank and the head. The method of making this joint must be operationally as simple as possible to retain the economies so far achieved, and must be so devised as to permit the utilisation of unspecialised labour. Supremely, it has to have the ability to ensure maximum and consistent quality of brazing.

Several methods of heating for such a process are available: flame heating by oxy-coal gas or oxy-acetylene; electrical resistance application; and high-frequency induction heating. Each method has its own advantages but the latter is particularly interesting insofar as it is possible, with suitable jigging, to arrange a semi-automatic operation to incorporate pre-set control of heating-cycle times and temperatures, with the applicator unit always at "immediate readiness". An added advantage is the assurance of cleanliness standards so essential to really good brazing. Basically, such a method would follow general R.F. heating practice and some appreciation of the principles involved might well be pertinent to further discussion.

high frequency induction heating

The development of high frequency induction heating — often referred to as "eddy-current" heating — issues from an astute exploitation of the causes generating heat in the laminated core of an electrical transformer operating at mains frequency.

Simple experiments show that when a current-carrying conductor is passed through a non-conductive surface upon which are scattered iron particles the latter become oriented in concentric circles around the conductor, indicating the presence of "sleeves" of magnetic flux. This effect is shown in Fig. 11(a).

The current, when "direct", is known to be distributed evenly over the whole of the cross-section of the conductor carrying it. When alternating, however, the current tends to concentrate at the outer surface of its conductor — a behaviour known as "skin effect". At mains frequency the loss of uniformity of distribution is quite small, but if the frequency is accelerated the concentration at the outer surface becomes more intense. When the conductor is "looped" or formed coil fashion, the flux field is displaced as shown in Fig. 11(b), the flux being no longer concentric but, due to the shorter path presented by the reduced inner periphery of the coil, re-orienting eccentric to the axis of the conductor,

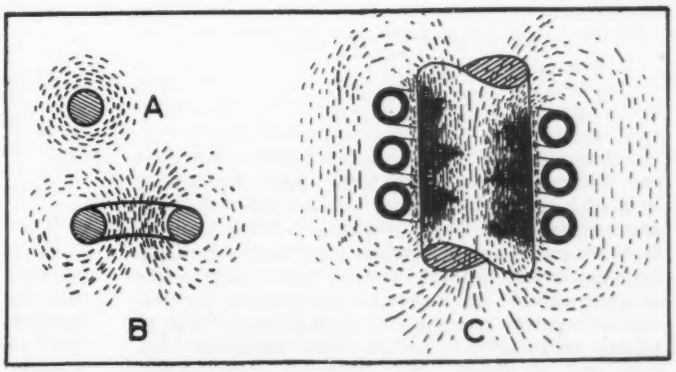


Fig. 11.

intensifying at the inside of the coil and "throwing-out" from the outer and greater circumference.

Insertion into the coil of an electrically conductive workpiece causes the induction of the eddy-currents into its mass, producing what is, in effect, a shorted secondary of a transformer — heating occurring at a rate relative to the frequency of the current alternation; the electrical resistivity and permeability of the workpiece; and the proximity of the surface of the material to the flux field. (Fig. 11(c).)

It follows, therefore, that adjustments of the annular gap between the workpiece surface and the inner "wall" of the conductor coil affects the penetration depth of the flux field and becomes a means of controlling the heating rate when the frequency is pre-set. Such adjustment is known as "coupling" — a "loose coupling", or wide gap, producing lower heating rates than a "tight coupling" — and extensive investigations into the true effects of these adjustments appear substantially to support the presupposition that the flux density at the surface of the work is proportional to the square of the coupling.

In view of the rather high power requirements, the coil, in practice, is made from thin-walled copper tubing through which cooling water is circulated, the power demand and, therefore, the size of unit necessary, being determined basically from the simple expression :

$$H = Me\frac{(t2 - t1)}{s} \text{ when :}$$

H = quantity of heat in B.T.U's.
M = mass of material limited to the section actually to be heated.
e = specific heat of the material.
t1 = pre-treatment temperature (°F).
t2 = ultimate temperature (°F).
s = heating cycle time.

Since 1 kW is equal approximately to 57 B.T.U's./min., conversion into electrical standards is simply accomplished.

The skin effect of the current, however, leads to rather high I^2R losses generating a potentially dangerous heating of the copper coil, and the quantity of water to be circulated should be of sufficient proportions to allow the dissipation of such heat in raising its own temperature; the power absorbed in so doing, and for which allowance should be made, being assessed from :

$$W = 0.147.Qt/10^3 \text{ when :}$$

W = power in watts.
Q = water flow (galls./min.).
t = temperature of coil (°F).

For metal melting, "through" heating and deep case-hardening of relatively large masses, frequencies in the 1 k/cs. - 10 k/cs. range produce the most satisfactory conditions, these frequencies being supplied from rotary equipment and in some cases spark-gap generators. But heating of small units such as the tungsten carbide heads requires less depth of penetration with greater concentration of flux density, both of which essentials are satisfactorily achieved with frequencies, generated by valve oscillatory equipment, of 450 k/cs. - 500 k/cs.

In actual fact, the determining more exactly of frequencies and power outputs required for a given application requires consideration also of losses due to convection, conduction, radiation and other incidental factors such as resistivity of the work coil itself and so on. Only rarely, however, are problems worked to such limits as, in any event, it would be peculiar indeed to consider other than a standard unit capable of power outputs reasonably in excess of basic requirements.

The advantages of eddy-current heating are clearly defined and readily appreciated, and an interesting evaluation of its economics is shown in Fig. 12. Whatever method is utilised as far as the production of rotary cutters is concerned — its contribution to the quality of the brazed joint is relative only to the efficiency of the heat application, the actual physical properties of the joint being the responsibility of the bonding medium.

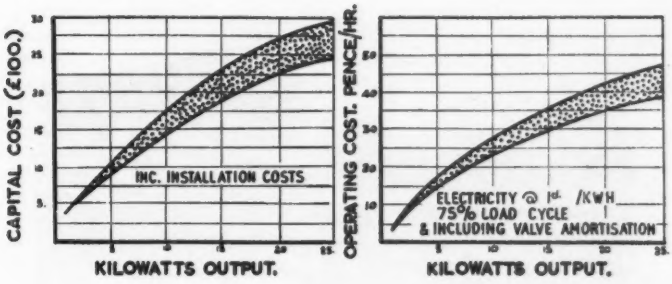
selection of the bonding medium

Apart from misuse by uninitiated operators, only very infrequently are tungsten carbide cutters required to be run up to red-heat and then only with the sacrificing of hardness characteristics as indicated in Fig. 7. Nevertheless, there are specific applications which require consideration of such conditions and, invariably, the "solid" carbide tool becomes the obvious choice; but in such instances where the steel-shanked cutter is to be subjected to these high temperatures, the bonding medium is usually copper with a melting point, dependent upon purity of material, of between 970°C and 1,083°C — or one of the copper/zinc alloys. Generally, the tool when competently used is not operated under conditions which generate saturation temperatures beyond 500°C. The use of a bonding medium which retains its properties at something like 20% in excess of that figure proves to give extremely satisfactory results, the properties demanded being :

(a) tensile strength approximating that of the shank;
(b) high ductility to accept the thermal stresses developed during the period of cooling from the brazing temperatures;
(c) ability readily to "wet" the surfaces of the dissimilar materials — tungsten carbide head and steel shank;
(d) high capillary performance;
(e) relatively low melting temperature to limit the cracking potential of the difference in the coefficients of thermal expansion — "straight" and compound tungsten carbides being respectively, $5.5(10)^{-6}$ and $6(10)^{-6}$ and steel : $11(10)^{-6}$;
(f) short melting range.

The "melting range" to which reference is made is of singular importance and has been investigated extremely thoroughly as a result of examinations of tools having failed during service through apparently inefficient brazing. A short explanation of the information gained as a result of these investigations will

Fig. 12.



be of considerable value in emphasising the importance of this " short melting range ".

Pure metals are endowed with distinct and assured melting " points " up to which they remain solid and at which they liquefy. Pure silver for instance melts at 961°C but its cost and characteristics prohibit its use. Copper liquefies at 1,083°C and, although possessing excellent properties as a bonding medium, is not satisfactory (apart from the instances where the finished tool is likely to be used at red heat) in view of the desirability for a low temperature brazing process. A 71% silver - 29% copper eutectic, however, melts at 778°C but such alloys require additions of other elements such as nickel and zinc to reduce further the melting temperature, and to confer higher strength and ductility. The modified composition, in consequence, loses its single melting " point " and acquires a melting " range ", the lower end of which is referred to as the " solidus " and the higher the " liquidus ".

At the solidus point in the brazing operation only a portion of the brazing alloy melts and " runs " into the capillary spaces between the shank face and the tungsten carbide head, leaving, momentarily, an unmelted proportion awaiting its own solidus temperature which is also the liquidus of the original mass. This portion may now no longer be in contact with its " carrier " element and is of different composition to that of the pre-solidus state. As a result it remains a " spacer ", preventing an intimate unification of the two surfaces or enforcing the necessity to increase the temperature beyond the specified range to dispel it into some functional usefulness. This failing is known as " liquation " and detracts from the efficiency desired as, even when melted by increase in temperature, the offending portion does not intermix evenly with that part preceding it into liquidus.

It becomes evident, therefore, that the liquidus must be reached as rapidly as possible after the solidus, a necessity which becomes a function of the heating rate and — with induction heating — of the coil coupling. Undoubtedly, considerable thought must be directed towards the acquisition of as short a melting " range " as possible, commensurate with maintenance of the physical properties previously mentioned.

Increasing the silver content lowers the melting temperature, shortens the melting " range " and reduces liquation tendencies. Thus, an alloy possessing the properties required, synonymous with a short melting range, will, inevitably, contain a relatively high percentage of silver, and a composition of 50% silver - 35% copper with a balanced remainder of nickel and zinc, subjected to extensive trials and microscopic exxamination, satisfies the specification with :

(a) tensile strength 35 tons/sq. in.
(b) elongation percentage 35;
(c) area reduction percentage 40;
(d) V.P.N. No. 138;
(e) melting range 634 - 653;
(f) capillary effect high;
(g) " wetting " effect high.

some aspects of the brazing process

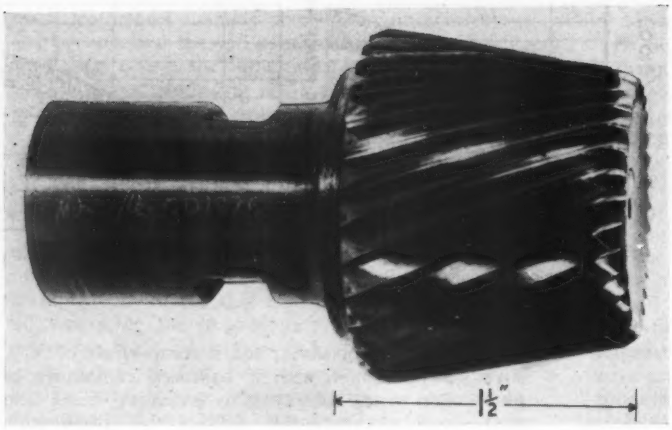
The futility of attempting efficiently to braze together two surfaces either of which is oxidised or otherwise contaminated is clearly recognised, and the removal of all such alien material is an essential prerequisite of successful bonding — the cleaning of the surfaces being accomplished, usually, by localised vapour-blasting, ultrasonic agitation or by off-hand grinding.

There is convincing proof, however, that none of these methods is sufficient in itself to ensure ideal conditions at the brazing moment, as atmospheric pollution alone may be sufficiently severe as to cause failure through progressive contamination immediately after the cleaning operation has been completed. For this reason immersion of the components in a bath of carbon tetra chloride (CCL_4) and their retention there until required for the pre-brazing fluxing operation, is essential — dissolution of grease traces and the release of loose particles also being assured.

the flux

Irrespective of the jigging method and the type of heating application, immediately upon removal from the CCL_4 bath oxidisation of the components recommences. Even more detrimental is the fact that as heat is generated during the bonding operation, further oxides are produced, and it becomes necessary to introduce into the brazing cycle some means of countering this behaviour. To perform this duty a chemical flux, the functions of which become manifold, is used.

Fluxes, in general, must have low surface tension characteristics enabling them readily to flow over



A 'special' tungsten carbide rotary cutter for machining fibreglass.

the joining surfaces. They must also assist in reducing the surface-tension of the molten braze metal, allowing the latter rapidly to "wet" the areas to be unified and require an inherent ability to dissolve oxidic formations, particularly the excesses produced in the heating period. In addition, it is essential that the flux should be capable of liquefying and becoming active at a few points below the solidus of the brazing alloy — to ensure complete "blanketing" of the fusion and to eliminate the possibilities of entrapments and inclusions — yet remain vigorously active at temperatures in excess of the liquidus of the braze metal.

Careful selection of a suitable flux, therefore, is of utmost importance. Trials with various compositions appear substantially to prove that, contrary to general suppositions, and distinctly opposing the recommendations of at least one of the foremost works of reference, borax alone is unsuitable as a flux for the silver alloys in view of the close tolerances of the melting temperatures involved. Development by flux manufacturers, aware of this problem, has resulted in the production of highly efficient compositions based on liberal use of the costly alkali-fluorides. Such fluxes, although accepting temperatures of 700°C to 750°C, remain fluid and fully active at less than 600°C, while retaining excellent oxide-solvent qualities and exhibiting ample evidence of the remaining characteristics required.

The brazing process in its entirety consists of a cleaning operation; application of flux and of braze metal in either paint form or as a flux paste and alternative forms of braze alloy; alignment of head and shank by jigging; process-timed induction heating, during which the head and shank are forced together as the alloy melts; ejection of the assembled components into a medium such as mica powder to ensure a slow cooling-rate; and post-braze inspection.

cutting of the teeth or flutes

The machining of tungsten carbide is a costly business, and throughout the engineering world an enormous amount of development work has been directed towards devising fast removal-rate methods with maximum economy. Electro-erosion and electrolytic grinding are perhaps the most successful of these efforts when applied to the more general type of hard-metal machining, but adaptation of these techniques for the cutting of sharp tooth-formations across progressively varying profiles presents some difficulties which have not yet been completely overcome. Of the remaining alternatives, apart from ultrasonic applications, grinding by silicon carbide and by diamond lapping remain superior. For the actual grinding of the tooth-formations in rotary cutters, the silicon carbide wheel is, of course, useless, through rapid loss of wheel-face configuration, and diamond lapping is probably the most efficient method available by which tungsten carbide is removed, leaving a high-quality finish; a consistency of configuration: and a minimum of "white-edge" — a term related to the crumbling of the cutting edges.

The technique of machining tungsten carbide with diamond tools has many facets, each of which being of equal importance to its neighbour in producing a balanced whole — a subject beyond the scope of this particular Paper. The diamond wheel construction itself, with diamond grading, mesh specification and concentration of impregnation factors to consider, is of cardinal importance, yet no more so than the determination of the economical speeds and feeds at which it must be used. Of equal concern is the workpiece finish; composition of the coolant — its flow rate and method of application; design of the wheel-spindle and machine as a whole; and methods for maintaining the configuration angles of the wheel to ensure consistency of tooth-form.

The unfortunate but necessary dismissal of these items in so summary a fashion may well infer a deprecation of their individual and collective importance, and it should be accepted that such an inference is contrary to fact. A similar understanding applies to the technique of cutting the teeth.

The fundamental principles of tooth formation — radial angles, axial, or helix angles and so on — as applied to conventional milling-cutter design, prevail in the early stages of rotary cutter development. But from there onward, functional similarities cease and

the comprehensive testing for "removal-rate/cutter-life" ratios over a wide range of materials — hardened die-steels and Nimonics to brass; ceramics to fibre-glass — indicates the necessary divergencies from the orthodox, the more important modifications affecting, principally, the pitch of the teeth and their radial angles or rake, the latter being almost invariably of negative aspect.

The need for adjustments in the radial angles of the tooth form from the conventional positive to a negative aspect is related to the low Izod values of cutting-grade tungsten carbides. A tooth form of positive aspect is subjected to maximum cutting pressures and impacts at its extremity, the position of maximum thrust tending towards fracture of the tooth along a line beginning at the location of initial impact and breaking out at a point only slightly below the rotational periphery of the cutter, the position of the line varying with the degree of radial rake and the ductility of the material being cut. Progressively, as the aspect is altered from positive to negative, the point of major thrust is moved inward and across the cutting face of the tooth to a location of greater cross-sectional area and greater strength. A limit is reached, however, at which "hammering" effects are introduced which stimulate the induction of work-hardening characteristics with diminshed stock-removal rates, and it becomes the function of the development work to define the optimum tooth form, different cutters requiring their own particular radial angles and helix.

Rake and helix, then, qualify as constants and cannot be altered once machined. But provided the tool is made available with a choice of tooth-pitch — fine and medium-cut, for instance, the remaining factors of speed and feed, as variables, can endow the cutter with considerable versatility.

Feeds, with a hand-operated tool of this type, are completely within the province of an operator's intellectual capacity to "feel" the best cutting rate, but unless some guidance on rotational speeds is made available to a user, the life of the tool, through the probable necessity for premature re-cutting of the teeth, is jeopardised. It is therefore incumbent upon the tool manufacturer to provide some operational advice and recommendations, thereby assisting the

Aluminium and Alloys

Brass; Copper; Cast irons

Mild Steel; Bronze

APPROXIMATE R.P.M. × 1,000	PERIPHERAL SPEEDS FT./MIN.					
Tool dia. (in.)	1000	1500	2000	3000	4000	5000
1/16	60	90	120			
1/8	30	45	60	90		
3/16	20	30	40	60	80	
1/4	15	22½	30	45	60	75
5/16	12	18	24	36	48	60
3/8	10	15	20	30	40	50
1/2	7½	11	15	22½	30	37½
5/8	6	9	12	18	24	30
3/4	5	7½	10	15	20	25
1	4	6	8	12	16	20

Fibre-glass

Hardened Steel
Stainless Steel
Nimonics;
Titanium, etc.
Ceramics

user to obtain maximum satisfaction while protecting himself against a possible adverse assessment, through unintentional misuse, of manufacturing quality.

The issue, or availability of such recommendations, would thus be in the form of a concise but assimilable presentation of the collated data derived from the whole exhaustive testing and research, and, with associated text, would tabulate the suggested speeds relative to given ranges of materials and cutter diameters. Some manufacturers prefer to use the tooth-pitch and a calculated constant factor is a guide to r.p.m., the simple expression—"$4(10)^5$/number of teeth = r.p.m."—indicating the idea behind such reasoning. Yet with dynamometer readings demonstrating the distinct relationships between tooth-loadings and V.P.N. values, together with ductility of workpiece material, it is quite clear that some amendments to recommended basic speeds are required to be shown so as to ensure as near as possible maximum efficiency of the tool on different materials. The associated Tables on the preceding page are a fair example of clarity based on functional evidence, graphic or nomogram presentation being avoided for the benefit of users who, generally in the majority, prefer to utilise tabulated references where more than a pair of factors is involved.

Achievement of such speeds is usually accomplished with pneumatic tools of the vane-motor type such as is shown in Fig. 1. No single air-tool, or any other known portable tool for that matter, can produce the whole range of speeds nor accept all the cutter types indicated, yet it would be out of the question for a using company to be expected to try to obtain sufficient different types of air-tools to cover the whole permutation. Manufacturers of rotary cutters, therefore, make and/or supply probably three of four different types of pneumatic tools, i.e., 10,000; 20,000; 40,000 and 90,000 r.p.m. in combination with which their cutters have been designed and tested, the intention being to enable a customer to select, from a sensibly limited range, an air-tool with r.p.m. most suitable for the types of cutter and material involver. A 20,000 r.p.m. driving medium, for instance, is generally quite satisfactory for use with cutters calling for 15,000 - 30,000 r.p.m., the "fringe" losses usually being comparatively slight; any finer adjustments for workpiece finish or stock-removal rates being made possible through the availability and careful selection of the "cut", or tooth-pitch, of any given cutter relative to an established r.p.m.

Innumerable occasions arise when tungsten carbide rotary cutters are required to be used in fixed-head machine tools and specialised rigs, particularly in the aircraft, rocket, and nuclear engineering fields. In such instances, feeds, speeds, cutter selection and characteristics must be more precisely co-ordinated and manufacturers are always quite willing to offer the benefits of their specialised knowledge and advice on such matters.

Irrespective of the method of application, however, some basic advice is made available together with the Tables of recommended speeds. A typical example is given on the facing page.

acknowledgments

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SELECTION AND USE OF TUNGSTEN CARBIDE ROTARY CUTTERS

The tungsten carbide rotary cutter is an expensive tool, yet, handled and operated with reasonable care, it should outlast its high-speed steel counterpart at least 50 times.

The predominant factors governing the efficient functioning of the tool are classified as follows:

1. selection of correct type

Rotary cutters can be supplied with coarse, medium or fine teeth, the differences being in the pitch of the teeth, their depth and their radial angles.

For rough machining, the coarse cut removes material more rapidly than the medium cut, the latter producing a better finish, but for high quality finishing the fine cut is necessary.

Two structurally different types are available; the solid carbide, i.e., shank and head of tungsten carbide; and the steel-shanked type.

For work requiring extreme pressures of application, the steel-shanked type is more suitable owing to the extra toughness of the shank, but tools with a maximum cutting diameter equal to, or less than, the shank diameter will be supplied only in the solid carbide form.

When cutters are likely to be used at red-heat, they must be ordered with this condition particularly emphasised.

2. speeds and feeds

The brittleness of tungsten carbide is allied to its hardness and the necessity for high rotational speeds is derived from the importance of minimising tooth-loading.

The optimum feed and speed relationship is usually found by experiment and practice, and is a compromise between machining time, finish and tool life. With a hand-operated tool, some individual acumen on the part of the operator is necessary — careful application at the commencement of each traversing movement; consistent pressure or "feel", and regular inspection of the tool to ensure that it is not used excessively after its wear demands re-cutting of the teeth. Wear becomes apparent when the application pressure/stock-removal ratio increases sufficiently noticeably to tend towards over-loading or stalling of the driving medium, and to cause undue heating of the cutter.

The tool must be kept moving. If the cutter is allowed to "sink" into the workpiece to any depth greater than a quarter of its diameter, "locking" will occur resulting probably in broken teeth. It should not be lightly skimmed over the workpiece but sufficient pressure should be applied to load the teeth and produce chips. "Skimming" will merely accelerate wear at the extreme cutting edges and ultimately excessive pressure will be required when deeper cuts are demanded.

3. chucking of the tool

The cutter, during its manufacture, is machined to ensure true rotational concentricity.

Impacts caused through rotational eccentricities create fractures in the cutting edges and it cannot be over-stressed that whatever chucking arrangement is used, it must be capable of holding the tool tightly and true, and as close to the head as possible.

4. rigidity of workpiece

The rigid holding of the workpiece, unless it is of sufficient mass and weight to produce its own rigidity, is of considerable importance — any "bouncing" of either the cutter or the work affecting adversely both the finish of the unit being machined and the life of the cutter.

5. coolant

The use of a coolant when machining the lighter alloys such as aluminium and magnesium is an advantage in reducing the tendency for the teeth to become "clogged" with the material. Normal soluble oil "suds", applied copiously, generally minimise this trouble.

Where the application of a coolant is impracticable, occasional lubrication of the tool with tallow or grease will be advantageous. Machining of other materials is better executed "dry" unless the cutter can be positively flooded with coolant.

6. general

When the cutter is not in use it should be stored in its specially designed protective container. It is essential to protect the cutter teeth from impact with other tools, etc., during storage and it should be returned for servicing before the teeth become so badly worn or damaged as to make re-cutting impracticable.

The Inspection Approach to the Essential Requirements for the Manufacture of Centre Lathes by Line Assembly

A Thesis by N. BROWN, A.M.I.Prod.E.

Chief Inspector,
T. S. Harrison & Sons, Ltd.

THE purpose behind the decision to manufacture centre lathes by line assembly was to increase the output of the Fitting Shop, using the same labour force; thereby reducing the cost of manufacture and also providing the means to incorporate additional features, giving better value for money.

The intention was to reduce costs of production and to enable a better product to be produced by paying more attention to good engineering features. These were to be incorporated without increasing the price to the customer, while giving him a more reliable and obviously better engineered product.

It was obvious that the role inspection would play in the achievement of these results would be important and the realisation of this only became fully apparent when difficulties were being dealt with.

The line assembly method was chosen because it contained inherent repetitive operations which ensured increased productivity and interchangeability of parts, the latter being a necessary feature of a successful assembly line.

This method of assembly is typified by the results achieved in the motor car industry and a study of its application to centre lathe manufacture reveals points of similarity; for example, when comparing the car engine with the lathe headstock, the transmission gearbox with the screwcutting feed gearbox. The fundamental difference, however, is in the tests against specification of the end product and which, in the case of the lathe, is primarily alignment of directional movement to very close limits of accuracy.

Relative values of degree of noise and freedom from vibration are other points of difference, but essentially alignment determines the whole problem of approach. Main requirements of car engine and gearbox include smooth, flexible and efficient transmission of power to the road wheels. Similarly the lathe must be free from torsional vibration but, in addition, close accuracy of alignment in various movements relative to the lathe spindle is absolutely necessary.

Good appearance is, of course, essential from a sales standpoint and the necessary use of sand castings in machine tools is a further difficulty, especially the contour matching of adjacent parts when compared to the uniformity of contour and surface finish normally achieved by metal pressings or plastic mouldings in the motor car.

As a necessary prelude to line assembly, the Machine Shop plant had been increased in output and quality so that the flow of components would be

satisfactory when the new method of assembly was introduced. The more general adoption of automatic equipment was to increase production of components of requisite accuracy to a predetermined rate, and it was determined that 200 sets of parts was the optimum batch quantity.

inspection considerations

It was obvious that new standards would have to be determined by careful analysis of assembly requirements and that effective liaison would have to be developed to ensure that disproportionate cost was not incurred in the Machine Shop.

The degree of success in this respect would also be the determining factor in assessing correct times for assembly operations.

During the transition period it was also essential that output must be maintained, as the new methods would have to be introduced into a Department already in existence.

human element

Realising the difficulty involved and the important part which would be played by the human element, the inspection personnel had been chosen with great care. Attainment of the new standards laid down would not be immediate and co-operation and patience in dealing with Machine Shop would be essential to obtain improved results. The possibility of reclamation of defective parts should be understood by the inspector and his assessment of what would be economically sound would be consequent upon his knowledge of Fitting and Machine Shops. To avoid recruiting a needlessly large staff to inspection, it was essential that the operations be reduced to a minimum. The prerequisite in this respect was to develop liaison with the Machine Shop and, as far as possible, to anticipate errors before they arose. The confidence of the chargehand, and even the machine operator, in the helpful attitude of the inspector is most important and a man of the right temperament in this respect is invaluable in the Inspection Department. At the same time, complaints from the Assembly Department must be tactfully dealt with so that constructive criticism is encouraged and not in any way stifled. A careful balance between the decision to ask Machine Shop to correct, or improve, the quality of a component must be tempered with the relative cost of reclamation in the Assembly Department.

standards and development

The new inspection standards could be established only as the new principles of assembly were developed but, in some cases, the methods were dependent upon the standards which could be consistently attained. As previously stated, line assembly achieves greater output because of the repetitive nature of operations performed. This is attained when the operations are as simple and effective as possible. The final assembly must be built up from basic sub-assemblies and the design of the machine must lend itself to this requirement in the flow line build-up of these assemblies into the finished product. The sub-assemblies must be such that final assembly can be performed in a straightforward manner to desired accuracy.

Primary analysis determined individual sub-assembly standards and detailed analysis then decided the accuracy of the individual components. An effort was made to ensure that parts were not produced to a greater degree of accuracy than was necessary, because it was realised there was a possibility that savings could be effected in this respect. A further factor which was considered was the need for interchangeability of components so that spares could be provided to give better customer service, but it was found that this was almost automatically ensured if sub-assemblies were to be produced satisfactorily. To reduce costs further it was also essential to prevent parts being assembled more than once, e.g., marking off for taper pinning or location dimples; where necessary, jigs and fixtures were recommended for this purpose. Filing or scraping had to be eliminated to the maximum degree, providing additional costs in Machine Shop were not out of proportion.

It is essential that the rhythm of line assembly must not be disturbed by the incorporation of defective elements, necessitating their replacement with consequent delay, and it is equally important that excuses for non-attainment of times set are not made on the grounds that sub-assemblies of inferior quality have required rectification or replacement. For example, in the case of the headstock sub-assembly, a Test Department was set up to simulate final running conditions as near as possible. In addition to recording temperature rise, spindle eccentricity and general noise level, test cuts on workpieces were taken to check freedom from rotational vibration and chatter.

Generally the method of approach, therefore, became the development of standards from assembly analysis so that final assembly could be completed direct and to requisite accuracy. Investigation into Machine Shop methods and equipment was then made to determine whether these standards could be attained and the formulation of inspection technique was effected to ensure, as far as possible, the smooth flow of parts of requisite quality being presented to Fitting Shop without elaboration.

Details are given in the following section of some the practical considerations involved.

machine shop problems

Research into the method of assembly from an inspection point of view was carried out to see just where improvements were needed in the machining of various parts in order to reduce assembly time. It was found that the major castings, i.e., bed, gearbox, apron, saddle and headstocks, would have to be machined to closer tolerances on related dimensions in order to reduce to a negligible amount the hand work necessary to effect the correct alignment between each assembly.

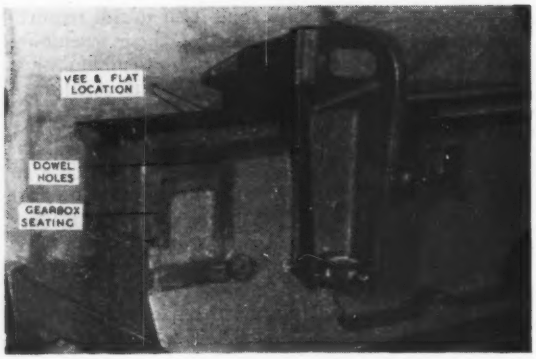

Fig. 1.

bed

Starting with the bed, the primary consideration is the correct relationship between the saddle ways, which are the front vee and the rear flat, and the lower front seatings on which the gearbox and support bracket are mounted. A special gauge was developed for use in the machining of the bed to check this relationship (Fig. 1). Locating from the saddleways it incorporated two dial gauges to read directly on to the gearbox settings. A master setting block was made to preset the gauge which was used by both Inspection Department and Machine Shop.

Jig drilling was further applied to the lathe bed to include the dowel holes which located the gearbox and shaft support bracket. The holes for securing the rack were also jigged so that it was possible to mount this direct without checking the vertical position with the apron pinion in assembled position.

saddle

On checking dimensional variations of the saddle and tracing back, it was found that casting distortion contributed largely to these errors. This called for a new approach in machining in order to keep distortion well within the limits which had been decided upon to cut hand work to a minimum at assembly. The technique evolved was to order castings well in advance of requirements in order to carry out rough machining, removing as much metal as possible; allowing to age and rough bedding before finish machining with light cuts, the casting being held by minimum clamping force. This had the effect of reducing general distortion from .010 in. to .003 in. in 12 in.; 75% being held within .001 in. per ft. A special gauge was also developed to enable the relationship of the apron seating to the vee and flat to be checked quickly and accurately. This gauge also located from the vee and flat and had two dial gauges reading directly on to the apron seating (Fig. 2). A master setting template was used in conjunction with it to check and reset the clock gauges if necessary. Jig drilling was also extended on the saddle to cover the dowel holes for locating the apron.

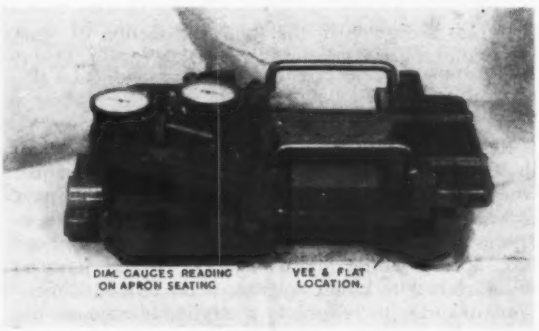

Fig. 2.

gearbox, apron and support bracket

On checking the gearbox, apron and support bracket, it was found that errors existed which necessitated a certain amount of hand work to correct. Whilst these errors were small, they were outside the required limits for direct assembly. On discussing this with the works engineer, it was decided to use certain jigs for drilling only and adding fixtures for fine boring operations. Clamping the castings in some of the jigs was found to introduce distortion and this was overcome by redesigning the jigs, taking special care in location of clamping points.

Discussions also took place with the Machine Shop foreman, chargehands and men, pointing out the need of greater cleanliness in use of equipment. The jigs must be clean from dust and chips, especially at location points, and the castings inserted were to be clean at the corresponding points. The most accurate jig can become useless by abuse and care must be exercised by the workman if the required results are to be achieved.

As this procedure became general, parts were produced within the required tolerance. The last step in bringing the gearbox, apron and shaft bracket in alignment with the saddle was to extend the jig drilling to cover dowel holes which locate these items on the bed.

headstock

The headstock is the principal assembly of a lathe and success or otherwise is dependent upon its smooth and efficient operation. The parallelism of the shafts, accuracy of centres, lack of vibration and close running of the gears, correct fitting and preloading of roller bearings are fundamental factors on which the quality of the machine depends.

In the particular lathe under consideration, the saddleways continue under the headstock and are the datum faces from which the headstock is located. The form milling of these faces on the underside of the headstock is the first operation. Subsequently the castings are multi-bored, registering in a fixture from the same points (Fig. 3). The errors produced by these methods, however, were considered to be greater than that which could be attained. Upon investigation, several factors were found to be contributory. The form milling of the datum faces was found to be

inconsistent. A simple bedding plate was made to check the castings after milling and any which were found twisted were rectified by hand scraping before the next operation. This had the effect of reducing the errors, but was not yet satisfactory. A further check on the boring machine revealed inaccuracies in the fixtures and in the alignment of the boring heads. These were realigned and set and the resulting components were then sufficiently accurate. A simple checking fixture was made, consisting of a base plate on which two dial indicators could be mounted to take readings in two planes simultaneously to check the accuracy of the main bores for alignment (Fig. 4). No difficulty was experienced in the other bores simultaneously produced with the main spindle bores, providing the latter boring was acceptable.

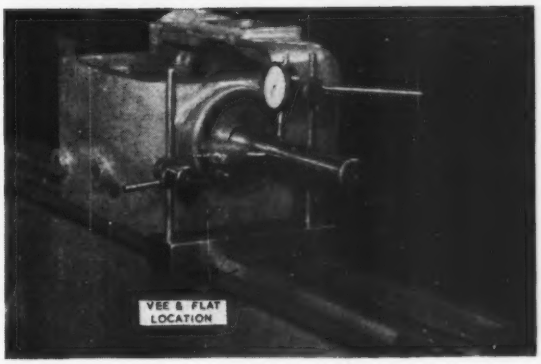

Fig. 4.

gearing

A quiet headstock at all speeds is very impressive to the buyer and reassuring to the operator. Noise indicates inaccuracies, even though these may be very small in the gears concerned. The reduction of noise to an acceptable level meant a closer review by inspection of all relevant inaccuracies and was, and still is, a most elusive goal.

Noisy involute gears are caused by:

1. malalignment of axes of mating gears;
2. pitch circle eccentricity;
3. tooth pitch error;
4. involute form inaccuracies;
5. lack of or incorrect tip relief on addendum of teeth;
6. heavy meshing at some point of rolling contact;
7. end bedding of teeth contact, due to out of parallelism of teeth with gear axis — a small error can be covered by final crown shaving;
8. dynamic out of balance.

Close fitting involute splines are used for mounting the gears to eliminate almost all radial play between gear and shaft. This involves accurate hardened and ground splined mandrels for turning, grinding, gear cutting and shaving. Frequent checks on mandrel accuracy have to be maintained and same replaced at regular intervals.

To minimise eccentricity, Machine Shop methods had to be developed to produce gear blanks which were virtually dead true for gear cutting purposes.

Gear cutting is carried out on modern machines and, if the mounting arbors are kept accurate and the gear blanks true and clean, then the cut gears are to the standard required for shaving. If all the prior requirements for gears have been maintained, then shaving covering a maximum metal removal of .001 in. will produce a form accurate enough to give smooth running. The maintenance of shaving cutters in a good and accurate condition involves an inspection routine which is essential to good gears. The cutting edges of the shaving cutter must be sharp enough to shave without work hardening and the contour of the tooth checked on an involute testing machine, deflections of the stylus being electronically amplified and charted on a graph recorder against a standard master (Fig. 5). No two cutters are absolutely identical and improved results have been attained purely by changing the shaving cutter in use.

Fig. 3.

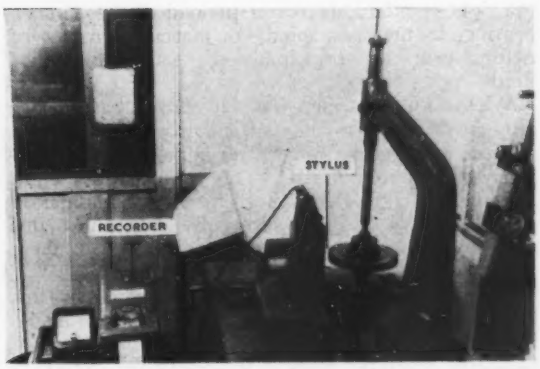

Fig. 5.

The amount of shaving must be kept to a minimum to avoid work hardening. Multi-lead hobs giving an accurate mean form but relatively coarse surface finish have been found to be of help in this direction.

The open type changewheel gear trains to the gearbox have been a major noise problem at high speeds. Reference back to Design resulted in the introduction of an intermediate fibre gear and this department are considering now the worthwhile enclosure in an oil bath of these gears.

An alert Inspection Department is an asset to Design and Development, indicating to them the weakness of present details and the difficulty involved in achieving and maintaining standards and suggesting new lines of approach. Recommendations to the Production Departments are also made where it is felt that the adoption of new techniques will reduce cost and yet maintain desired standards.

assembly testing

Sub-assembly inspection standards are very important. Each sub-assembly must be interchangeable and inspected on all relevant points before being passed forward for inclusion in final assembly. Requirements have to be such that the final assembly goes forward smoothly without interruption and with the minimum of rectification, so that the final assembled machine is of the quality desired.

headstock sub-assembly

On completion of the headstock it is necessary that the unit be put through a number of tests before passing off for inclusion in the final assembly. To do this, each headstock is mounted on a test lathe and the necessary driving belts are connected thereto. The spindle is now run through the range of speeds to check for smoothness of operation and that the noise level at each speed is within the required limits. This test involves examination of the preloading of the spindle. Rough and finish turning test cuts are made at each speed to ensure spindle rigidity and to check the smoothness of finish. Usually the roughing cuts were satisfactory if the detail components were of the quality required, but the desired finish was more difficult from the point of view of maintenance of the right standard. Incorrect preload of the Timken bearings on the main spindle or inaccurate rolling of mating gears are principally the cause of inferior finish.

When the gearing was at fault, satisfactory alternative gears for this particular speed were used and the reject gears reshaved to improve the form to give the required finish. This involved a certain amount of trial and error until the right combination produced the right finish. By pursuing this methodical process of elimination, each of these points was checked and made satisfactory.

Erratic operation of the machine caused by unbalance, to which reference has previously been made, was finally prevented by the use of an electronic balancing machine. Spindle sub-assemblies, complete with all rotating masses, are now balanced in an adjoining department to the Finished Parts Stores; tested units are stored *en bloc* until required in the Fitting Shop.

The headstocks were then run at lowest and highest speeds in order to check temperature levels, and excessive heat generated at higher speeds usually involved purely the readjustment of the Timken bearing preload.

To eliminate the latter difficulty, a torque test which measured freedom of spindle rotation was introduced in conjunction with Messrs. Timken Ltd., the actual reading of the spring balance being previously determined by experiment.

It had been hoped that standards would be developed for the gear tooth form which could be regularly produced and checked on the involute form testing machine to such a degree of accuracy as to eliminate the trial and error method of assembly, but this was not found feasible. Preliminary testing as described did, however, ensure that errors were corrected before final assembly and a smooth flow to the finished condition was thereby attained.

saddle and slide assemblies

The saddle front vee and rear flat are checked against a master for bedding at the same time as the cross slideways are checked for squareness. In scraping the saddle bearing surfaces, any variation that occurred in the squareness was simultaneously corrected. Saddles which had passed inspection in the Machine Shop were sometimes distorted when inspected at sub-assembly. This was due to the settling of the castings and, after due consideration had been given to the possibility of artificial ageing, it was found that less trouble was experienced if a lapse of time, involving two or three months, was allowed prior to sub-assembly. Corrections made in the Machine Shop at this point were then usually permanent and no further distortion occurred.

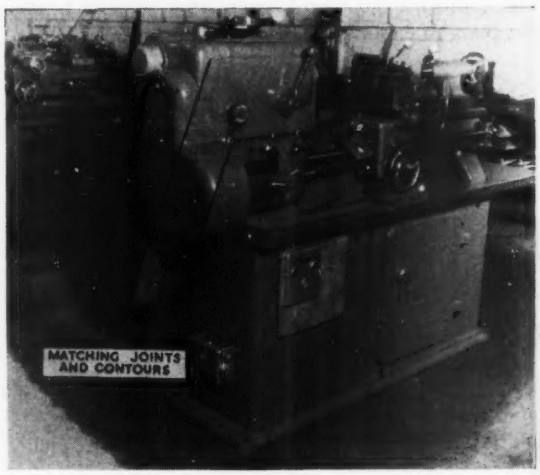

Fig. 6.

apron and gearbox

The apron sub-assemblies were more straightforward and did not involve any final assembly difficulty. The gear boxes had to be checked for free running at all feeds, primarily on the tumbler assembly, and these were mounted on a sub-assembly test fixture and driven at high speed to ensure that noise was within prescribed limits and particularly that the meshing of the tumbler gears was correct.

final assembly

When the lathe is finally erected, alignment tests are conducted to The Institution of Mechanical Engineers and The Institution of Production Engineers Acceptance Tests for Machine Tools, and turning tests are made over the full range of speeds and sample feeds as a check on previous sub-assembly results.

foundry requirements

appearance

The finished appearance of the lathe to a large extent depends upon the quality of the castings and, in particular, to the mating of associated contours (Fig. 6). In this respect a good deal of liaison was necessary between factory and foundry to achieve satisfactory results.

datums

The first step was to establish datum points to which first operation machining could be referred. The best locations had to be determined in conjunction with the Machine Shop and the Assembly Department and appropriate fixtures were modified where necessary to achieve the required blend between adjacent castings. The information thus obtained was duly conveyed to the foundry and the decision made regarding the method to be employed in order to produce castings with minimum variation relative to the datum points. The decision also included other deviations from casting uniformity such as flashings, coreholes, etc., so that it was clearly understood what standards were required and what would be accepted. This introduction of casting inspection tests saved considerable time in Machine and Erection Shops.

patterns

If patterns are in use too long without repair, or if the foundry do not keep their moulding boxes, and particularly the locating pins, in good condition, errors become apparent in the castings. This can cause considerable delay in the Machine Shop, so a constant check on castings is repaid by higher productivity.

summary

The effective operation of inspection calls for an intimate knowledge of Machine Shop and Erection Department techniques, practice and procedure. The unquestioning acceptance of inspection decisions is something that is aimed at, but very rarely completely achieved. The proof of the correctness and wisdom of past decisions paves the way to future confidence. Any laxity or indifference very soon upsets what has been gained by a struggle.

Good work is not purely a reflection of the efficiency of the Inspection Department, but is the result of team work and collaboration between the departments involved. The quality of a machinist's or fitter's work is the concern of his chargehand or foreman as much as that of the inspector. An operator should be confident of the quality of his work, but the inspector safeguards the maintenance of the set standards and can advise the operator of the steps he should take to help in meeting them.

Within reason, discussion initiated by the Inspection Department on any aspect of manufacture can lead to helpful decisions, but the final word must rest with the departmental authority delegated to that responsibility.

At all stages the simplification of inspection techniques has been carefully borne in mind, and the elimination of unnecessary measurement in proportion to the development of consistent machining methods has been effected wherever possible.

Checking fixtures, such as shown in Figs. 7 and 8, and elsewhere in the Paper, for determining critical dimensions of associated parts have been utilised whenever an opportunity was presented.

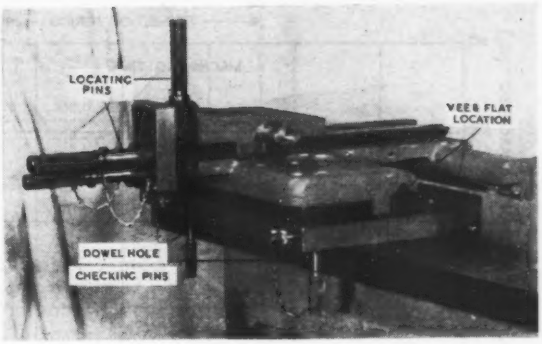

Fig. 7.

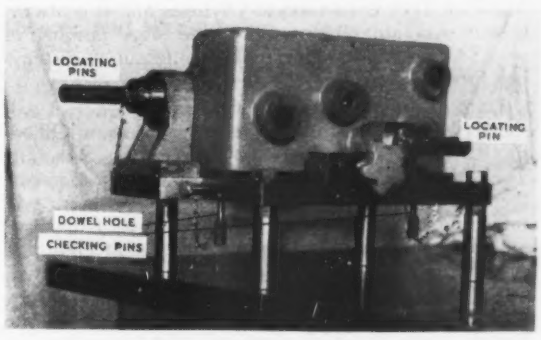

Fig. 8.

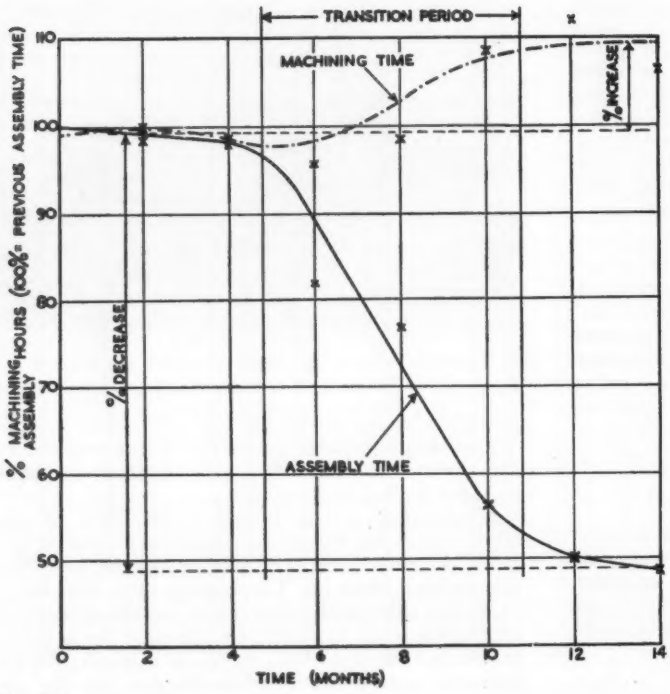

Fig. 9.

The guiding principle throughout has been that delay or dis-assembly is intolerable in line assembly, but if effective methods are developed to obviate this condition, tremendous results can be achieved. Proof of this statement will be seen by an examination of the chart at Fig. 9, from which a saving of 50% in assembly time has been attained at the expense of an additional 10% machining time.

acknowledgment

The writer would sincerely thank the management of Messrs. T. S. Harrison & Sons Ltd. and, in particular, the Works Director, Mr. D. H. Turnbull, M.I.Prod.E., for the facilities granted by which the production of this Paper was made possible.

The chart and photographs are reproduced by their kind permission.

Correspondence

From : **2nd.-Lieut. M. W. Hancock, Grad.I.Prod.E., 23 Base Workshops, R.E.M.E., B.F.P.O. 20.**

Decline of British Machine Tool Industry

I know the British as a race are quick to criticise themselves but I would like to criticise in a practical light and illustrate the decline of the British machine tool industry.

As a young qualified production engineer it has been my custom in civilian life to visit the British Machine Tool Exhibition at Olympia and it is always a source of amazement to see the large number of so-called British machine tool manufacturers displaying foreign machines.

I am at present stationed in Germany where I will shortly be finishing my National Service as an Officer in R.E.M.E., and recently visited the Machine Tool Exhibition in Hanover. It is difficult to describe the vast area this exhibition covers but I think it will suffice to say that the floor area taken up by machine tools is some six times greater than that at Olympia. A total of more then 777 separate firms exhibited, out of which over 650 were German manufacturers. Of the 123 odd foreign exhibitors, only about 14 were British, some of which were still displaying foreign machines.

The question we must ask is how can one country, which only a few years ago was crippled by war, stage such a magnificent exhibition showing the world its unchallenged skill and vast industrial wealth and potential? Could the answer to this be that the British machine tool manufacturer is too content to make his money by selling foreign machines, rather than spend money on developing his own industry? Certain of the large British machine tool manufacturers no longer really need a factory, as they invariably offer a foreign machine in preference to a machine they make, or could make with a little thought and effort.

If Britain were to join the European Common Market, then it is more than likely that the British machine tool industry as a productive body would finish, and it would become a "clearing house", feeding foreign machines to industry. Until our machine tool industry completely collapses, it is up to organisations such as PERA to try and shoulder the burden of development and research on limited funds from industry. Compare this with development in Germany, Italy, France and Switzerland, where machine manufacturers are pouring money, aided by their Governments, into development and expansion.

The only expansion done by the British machine tool industry seems to be that of rapidly expanding sales organisations to deal with selling to British industry the ever-increasing numbers of foreign machine tools.

Quarterly Newsletter to the Institution

Fifteenth Annual General Meeting

The 15th Annual General Meeting of the Association was recently held at Melton Mowbray.

Sir William Stanier, F.R.S., was re-elected President of the Association. The following were newly elected to PERA Council :

Mr. G. F. Shrigley (Humber Ltd.);
Mr. R. H. S. Turner (A.E.I.(Manchester) Ltd.).

The following retiring members of Council were re-elected :

Mr. L. L. Bott (Davey, Paxman & Co. Ltd.);
Mr. J. O. Bowley (A.E.C. Ltd.);
Mr. F. V. Everard (Belliss & Morcom Ltd.);
Mr. W. M. Hurton (English Electric Co. Ltd.);
Mr. E. A. Hyde (Wickman Ltd.);
Mr. F. P. Laurens (International Computers & Tabulators Ltd.).

At a Council Meeting on the same day, Sir Basil Tangye (Tangyes Ltd.) was re-elected Chairman of Council. Mr. A. L. Stuchbery (Metal Box Co. Ltd.) and Mr. G. Ronald Pryor (Edward Pryor & Son Ltd.) were also re-elected Vice-Chairmen of Council.

Chairman's Report

The Chairman's Report stated that work on 39 general investigations was carried out during 1959 on press-working, machine tools, blanking and piercing, cutting tools, high-speed hobbing, cold extrusion of steel, automation lubricants, thread rolling, vibration, ceramic tools, hydrostatic slideways, etc. During the year 27 sponsored investigations were completed and 35 new investigations of this type were initiated on behalf of individual firms; in addition, 284 practical investigations were completed. These investigations have included the measurement and analysis of sources of vibration in machine tools, studies of the application of non-metallic materials to slideways, development of special-purpose machines, etc.

The number of technical enquiries submitted by members again increased substantially during the year to about 4,000 and there was also a large increase in the number of sponsored technical investigations. This work included the design of various types of production equipment, improvements in factory layout, work handling, process planning, work study, efficiency surveys, re-designing products for more economical manufacture, etc. A number of firms also retained PERA engineers continuously to advise on the reduction of manufacturing costs. Considerable interest has been raised in many countries by PERA's cover-to-cover translations of Russian technical journals under the titles " Machines & Tooling " and " Russian Engineering Journal ". Both journals continue to provide convincing evidence of the rapid progress being made by Russia in many fields of production.

Education and Training

Heavy demands were also made by members on the educational services. Several of the intensive five-day courses for managers, production engineers, foremen, planning engineers, etc., were modified to take account of recent developments in production techniques and equipment. Specialised courses on metal cutting were also revised to allow more time for practical demonstration as additional machinery had been acquired for the demonstration workshop. The series of two-day refresher courses for engineering personnel was also extended. In addition to courses on tool and cutter grinding, machine tool alignment and performance testing, and machine maintenance, courses are also now available on inspection and quality control.

Management Economics

The Report also refers to the rapid growth of the new Department of Management Economics set up last year to assist members with organisational problems, production control, administrative systems, paper-work simplification, etc. The Department is conducting assignments in the production, commercial and financial departments of many large and small companies, and has sucessfully implemented its recommendations over a very wide field.

Income and Membership

Income for the year totalled £341,838, an increase of £51,691 over 1958. This has allowed the Association to expand the staff and facilities and extend the scope of the services available to members.

At the end of 1959, membership had risen to 798 companies, an increase of 61 over the previous year. The number of Associate Members (Technical Colleges and Engineering Departments of Universities) increased slightly during 1959. To ensure maximum co-operation between Associate Members and the Association, a College Co-ordinating Committee was formed in 1959 and met at PERA on two occasions during the year.

National Conference, Brighton

The Institution's National Conference on "Modern Trends in the Manipulation of Metals", which took place last month at Brighton, was attended by over 350 members and non-members, with their ladies.

The excellence of the Papers presented and the lively discussions which followed combined to make this a most successful gathering, from which those present derived much interest and value, while the Civic Reception and Dance, when members of the Conference and their ladies were received by the Mayor and Mayoress of Brighton, Alderman and Mrs. A. J. M. Johnson, and the Presidential Reception and Dance on the final evening, were thoroughly enjoyed.

The Conference Proceedings will be published in *The Production Engineer,* commencing with the January, 1961, issue. Preprints of most of the Papers presented may be obtained from the Publications Department, 10 Chesterfield Street, Mayfair, London, W.1, price 3s. 6d. each, post free.

Lord Austin Prize Award, 1960

This Award, which is open to all Student and Graduate members of the Institution between the ages of 21 and 30 years inclusive, is made annually for the best essay on one of three subjects.

The closing date of entry for the 1960 Prize, is Saturday, 31st December, 1960.

Full details regarding the Terms of Reference of the Prize and the subjects set for this year are available from The Registrar, The Institution of Production Engineers, 10 Chesterfield Street, Mayfair, London, W.1.

The Control of Production Processes

A Course for Works, Plant and Production Engineers, on "The Control of Production Processes", is being held in the University of Nottingham during the winter, terminating on 21st February, 1961. This is the sixth Course of this kind, the syllabus being derived from the requests of those who attended the last course. It consists of 15 meetings, held in the new First Year Teaching Building of the Applied Science Faculty, from 7 p.m. to 9 p.m.

Non-transferable registrations may be made in the name of individuals at a fee of five guineas; transferable registrations in the name of a firm or organisation at a fee of six guineas. Full details may be obtained from The Organising Secretary, Engineers Course, 1960, Faculty of Applied Science, The University, Nottingham.

NEWS OF MEMBERS

Mr. T. D. Walshaw, Member, has recently relinquished his appointment as Head of the Engineering Department at Darlington College of Further Education, to take up the post of Head of Mechanical and Civil Engineering Department at the Harris College, Preston.

Mr. G. A. Blackshield, Associate Member, has been appointed Assistant Sales Manager to Impregnated Diamond Products Limited, Gloucester.

Mr. N. A. Butterworth, Associate Member, is now Senior Lecturer in Production Engineering at the Harris College, Preston. Mr. Butterworth, who is a member of the Preston Section Committee, also serves on the Institution's Standards Committee.

Mr. F. A. Checkley, Associate Member, is now Chief Draughtsman, Tool Design, with James Howdern & Co. Ltd., Glasgow.

Mr. L. M. Harman, Associate Member, has taken up an appointment lecturing on Production Engineering at the Maidstone Technical College.

Mr. F. Knighton, Associate Member, has taken up an appointment as Senior Lecturer at the Mid-Warwickshire College of Further Education, Leamington Spa.

Mr. L. Magee, Associate Member, has recently joined joined Messrs. Head Wrightson Steel Foundries Ltd., as Works Manager, Teesdale. Mr. Magee was formerly with Messrs. Crofts (Engineers) Ltd., Bradford.

Mr. Alexander McKay, Associate Member, has been appointed Works Manager of The L. S. Starrett Co. Ltd., Jedburgh, Roxburghshire. He joined the Company in September, 1958. Mr. McKay was a member of the Dundee Section Committee, and was at one time a part-time teacher in engineering subjects at Dundee Technical College.

Mr. Lionel Robinson, Associate Member, has relinquished his position of Production and Technical Manager at the Production Engineering factory of J. Lyons & Company Ltd., and has taken up an appointment as Group Production Engineer with Powell Duffryn's consulting company, Powell Duffryn Technical Services Ltd.

Mr. H. M. Falconer, Associate Member, has recently left the United Kingdom to take up an appointment as Polysius Resident Engineer for the Duncan Stratton & Co. (U.K.) Ltd., Karachi.

Mr. G. Yates, Associate Member, has relinquished his position of Assistant Lecturer Grade "B" at the Walker Technical College, Oakengates, Shropshire, and has taken up an appointment in Production Engineering subjects at the Reading Technical College, Reading.

Mr. R. B. Wilkinson, Associate Member, formerly Manager of the Sunderland Factory of Bristol Siddeley Engines Ltd., has been appointed Chief Buyer (Bristol Factories).

Mr. J. Winstone, Associate Member, has been appointed Production Manager with Morris Motors Ltd., Radiators Branch (Oxford and Llanelly).

Mr. G. Winton, Associate Member, is now Plant and Services Works Manager with James A. Jobling & Co. Ltd., Sunderland.

Mr. J. E. Adlington, Graduate, has left I.C.I. Ltd., Billingham Division, County Durham, and has taken up an appointment as a Mechanical Engineer with the Ministry of Works, Northern Nigeria.

Mr. A. G. Callimachos, Graduate, has won a scholarship from the French Government for nine months further studies in engineering at the Ecole Nationale Supérieure d'Electricité et de Méchanique, University of Nancy.

Mr. W. Jenkinson, Graduate, has taken up an appointment with the North Riding Education Authority as an Assistant Lecturer Grade "B" at the Cleveland Technical College, Redcar.

Mr. K. Seshadri, Graduate, has relinquished his position of Senior Jig and Tool Designer at Lockheed Brake Co. Ltd., Leamington Spa, and has now joined the University of Khartoum, in their Faculty of Engineering.

Mr. M. J. Walsh, Graduate, has now left The English Electric Co., in Liverpool and has taken up an appointment with The United States Time Corporation in Dundee, Scotland, as Production Control Manager responsible for Production Control activities on the Continent and in Great Britain.

DIARY FOR 1960-1961

NOVEMBER 10 ... ... **The 1960 Sir Alfred Herbert Paper,** at The Royal Institution, London.

Speaker : **Professor R. E. Lane,** Nuffield Department of Occupational Health, University of Manchester.

Subject : **"Health Services in Industry."**

1961

FEBRUARY 9 ... ... **The 1960 Lord Sempill Paper,** at The Royal Institution, London.
(changed date)

Speaker : **Sir Percy Hunting,** F.C.I.S.

Subject : **"The World's Future Transport Requirements."**

MAY 24 ... ... **The 1961 Viscount Nuffield Paper,** at The University of Bristol.

Speaker : **Sir Willis Jackson,** F.R.S., Director of Research and Education, A.E.I. (Manchester) Ltd.

NEW BRITISH STANDARDS

Copies of the following British Standards, recently issued, may be obtained from the British Standards Institute, 2 Park Street, London, W.1, at the prices stated.

B.S. 1748 : —— Methods for the analysis of copper alloys. B.S. 1748 Part 6 : 1960 **Tin (nickel coil reduction method). 3s. 0d. B.S. 1748 Part 7 :** 1960 **Silicon (photometric method). 3s. 0d. B.S. 1748 Part 8 :** 1960 **Phosphorus (photometric method). 3s. 0d.**

B.S. 1831 Supplement 2 : 1957 **(Ref. PD3866) — Recommended common names for pesticides. 2s. 0d.**

B.S. 3228 : —— Procedures for obtaining properties of steel at elevated temperatures. B.S. 3228 Part 1 : 1960 **Proof stress. 3s. 0d.**

B.S. 3248 : 1960 **Sparkguards for solid fuel fires. 3s. 0d.**

B.S. 3251 : 1960 **Hydrant indicator plates. 4s. 0d.**

B.S. 3252 : 1960 **Ingot tin. 4s. 0d.**

B.S.3253 : 1960 **Phenolic-resin bonded asbestos-paper sheets for electrical insulation at power frequencies. 6s. 0d.**

B.S. 3254 : 1960 **Seat belt assemblies for motor vehicles. 4s. 6d.**

B.S. 3255 : 1960 **Presspaper for electrical purposes. 6s. 0d.**

B.S. 3256 : 1960 **Small fusion-welded air reservoirs for road and railway vehicles. 6s. 0d.**

B.S. 3257 : 1960 **Principles and terms for the description of fabrics (with special reference to fibre contents). 5s. 0d.**

B.S. 3259 : 1960 **Peters' aural specula. 3s. 0d.**

ISO RECOMMENDATIONS

ISO/R104 : Ball and roller bearings — boundary dimensions. 5s. 0d.

ISO/R113 : Ball and roller bearings accessories. 5s. 0d.

Hazleton Memorial Library

ADDITIONS

Members are reminded of the following Library rule, which is frequently ignored:

"The initial loan period is one month, and borrowers may keep books and periodicals for further periods of one month, if they ask the Librarian, and if no other borrower wants them. Applications for renewal may be made by post or telephone."

Benge, R. C. **"Technical and Vocational Education in the United Kingdom: a Bibliographical Survey."** *Paris, UNESCO,* 1958. 51 *pages*

One of a series of bibliographies published by UNESCO intended to illustrate the development and present state of technical and vocational education in member countries. There are informative annotations, and a detailed subject index.

Eisler, Paul. **"Technology of Printed Circuits: the Foil Technique of Electronic Production."** *London, Heywood,* 1960. 405 *pages. Illustrated Diagrams.* 60s. 0d.

The author briefly surveys other techniques of prefabrication, but concentrates chiefly on the foil technique of electronic circuit production which was invented by himself. The book is a guide to practice, and an account of the more academic aspects of the subject. There is an extensive and useful bibliography.

Contents:- The basic story of printed circuits — The confused start of a new technology (Papers by Dr. C. Brunetti; J. A. Sargrove; and C. W. A. Dunner) — The principles of method selection and the foil technique — Watching printed circuit production — From the drawing to the photo-stencil — Litho printing — Photochemical printing processes — Plating and foil technique — Ancillary operations — Laboratory routine — Design — Conventional components for assembly with printed circuits — Printed circuit trouble shooting — Automatic assembly in the electronics industry — Regeneration of ferric chloride — Weight saving and heat dissipation — Miniaturization — Printed components — Microwave printed circuits; a short survey — Printed circuits and the electronics industry — Appendix 1. Examples of commercially available adhesives for foil bonding — Appendix 2. The control of strength of etching solutions — Double life layer process — Plating solutions and some principles of the automatic plating plant. Description of R.C.A. programmed punching machine — Approximate analysis of the characteristic impedance of flat strip transmission lines — Characteristics of flat strip transmission lines of importance in applications — Bibliography.

Slaymaker, R. P. **"Mechanical Design and Analysis."** *New York, Wiley; London, Chapman and Hall,* 1959. 418 *pages. Illustrated. Diagrams. Tables.* 76s. 0d.

This is a text-book for an undergraduate course in machine design. Part 1 (pages 1 - 92), deals with a few topics essential to the machine designer, with which the student may not already be familiar. Part 2 is an expression of the author's conviction as a teacher of engineers, that individuals are more readily interested in the details of a specific problem, than in the theory embodied in the problem. The author, therefore, departs from the common "theory followed by problem" method of presentation, in which the problems are exercises in the use of theory and usually have one answer; and presents instead a collection of projects based on real industrial design problems in a variety of named companies. These create a need for theory, and have a variety of solutions. There is an abstract at the beginning of each project for the benefit of the instructor, but the projects themselves are directed to the student. The first five are such as a young engineer might be expected to undertake without much supervision; the rest are successively more demanding of creative thought, and more difficult. The text is interspersed with series of exercise problems based upon the project, with suggested procedures for answering them. The usual preliminary reviews of basic subjects such as mechanics, strength of materials, and metallurgy, are omitted, because the author prefers the student to use the fundamental texts on these subjects, at the time he needs to, rather than a pre-printed summary at the beginning of the course.

The author's aim is to "give the student confidence by showing him that he can solve engineering problems with the fundamental tools he already possesses rather than to burden him with a set of special tools to fit every problem he may encounter".

Contents:- *Part* 1. *General Topics.* Introduction — Limit dimensioning — Materials and processes — Cyclic loads, stress concentrations, factors of safety and working stresses. *Part* 2. *Specific Projects.* A drive shaft layout problem — Magazine feed for a Bliss press — Redesign of a commutator assembly — Available force in a squeeze riveter — Alternate details of a hand crank — A few creative problems — The drive shaft of an impact extrusion press — Critical speed for a shaft assembly — The leaf spring of a tractor for a tractor trailer combination—A relief valve spring for a flow control valve—Bearing cap bolts for an automobile connecting rod—The rods for a steering system—Metal-clad rubber bushings—Sleeve bearings for a gear reduction unit — Needle bearings and planetary gear trains — Kinematic design of spur gears — Strength and durability of involute spur gears — A work and gear speed reducer for an electric furnace hoist — Bevel gear layout and design — Air brakes for the front dolly of an electric loader — Belt drive for a compressor.

United Nations, Geneva. **"Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy."** *Geneva,* 1958. Volume 19. **"The Use of Isotopes: Industrial Use."** *Geneva, the United Nations,* 1958. 366 *pages. Illustrated. Diagrams.*

Contents:- *Session* 5*b. Progress in the use of isotopes.* Erwell and Ljunggren. Recent use of radioisotopes in Sweden — Spinks. Applications of isotopes in research and control — Putnam. Industrial application of radioisotopes — Luoto and Rotkirch. Tracer techniques in Finnish industry — Leveque et al. New applications of radioelements in France — Fisher and Cassin. Production and use of radioisotopes in France — Atomic Energy Bureau. Radioisotopes and high energy radiation in Japan — Baimler.. Non-destructive testing in Czechoslovakia — Topchief et al. Applications of radioisotopes — Aebersold and Fowler. Developments in industrial applications of radioisotopes — Libby. The Atomic triad — Pochin. Medical value of radioisotope localisation — Record of session. *Session D-7. The use of isotopes in industry.* New developments reported to the conference — Erwell. Solid-liquid interfaces and surface layers — Schultz et al. Use of activation in isotope techniques —

Rumyantsev and Matsyuk. Isotopes for checking thin-walled products — Cook et al. Isotopic fluorescent X-ray production and applications — Oshida et al. Non destructive inspection in Japan — Deterding and Calow. Engine wear measurement in moving vehicles — Zaslavsky et al. Action of anticorrosive additives — Pavelesco and Iliuc. Radioisotope study of lubricant film thickness— Owaki et al. Industrial measuring equipment in Japan — Green and Cheek. Low energy photon sources for industry — Danguy and Grard. Measurement of thin layers by backscattering — Bogdanova et al. Radioisotopes in metallurgical research — Gruzin et al. Diffusion elements in zirconium and titanium alloys — Simnad. Advances in metallurgical research — Saito. Process analysis in the chemical and metal industries — Abid Husain. Investigations of backscattered Beta radiation — Fodor and Varga. Determination of tungsten in steels by backscattering — Brook et al. Radiographic and radiometric study of metals — Fodor and Varga. Phosphorus analysis in steel by isotope dilution — Varga and Fodor. Inspecting the technology of a continuous casting — Bozoky. Current efficiency in aluminium furnaces — Eiecholz and Roberts. The adsorption of tracers on mineral particles — Plaksin. Flotation studies with radiography and radiometry — Llopis et al. Tracer study of reaction of copper with polysulphides — Herrman et al. Tracer study of antimony migration in a lead battery — Reiffel. Measurement and control methods using radiation — Berthold. Continuous measuring of hydrogen in hydrocarbons — Levin et al. Rapid bacteriological detection and identification — Gotte. Fission products as tracers in chemistry — Shumilovsky, et. al. Relay instruments using radioactive isotopes — Weinzierl and Mayerhofer. A recording method for water-level fluctuations — Trost. Control and measurement of levels and densities — Hull and Macomber. Flow measurements by the total-count method — Pecsock et al. Radiation in sanitary engineering — Sauerwein and Hossner. Investigations into carrying fine coal — Peteou. Radioactive tracers in oil extraction in Roumania — Inman and Chamberlain. Tracing beach sand movement with radio-active sand — Gilbert et al. Tracing undersea sand movement with radioactive silver — Reifenschweiler. A suitable tritium carrier for gas discharge tubes — Record of session.

Wilson, Robert F. **"Colour in Industry Today: A practical Book on the Functional Use of Colour."** *London, Allen and Unwin,* 1960. 90 *pages. Colour plates.*

The functional, as opposed to the older symbolic or purely aesthetic, approach to the subject of colour is emphasised in this book. The principles of the science of colour, the psychology of colour, and its practical applications are dealt with. The author stresses the advantages to industry of planned colour schemes, which include such benefits as increased productivity, less absenteeism, reduced accident rates; and he urges the close co-operation of colour consultants and lighting engineers.

Contents:- Widening horizons — Colour vision — The psychology of colour — The uses of colour (e.g., Safety colours; machinery colours; identification colours) — Lighting in industry — Seeing and planning — Suggested colour schemes — Hospitals and schools.

Woodbury, Robert S. **"History of the Gear Cutting Machine: an historical study in geometry and machines"** *Cambridge, Mass., Massachusetts Institute of Technology, Technology Press,* 1958. 135 *pages. Illustrated. Diagrams.* (Technology Monographs. Historical Series, No. 1.)

The history of the gear cutting machine begins early in the 16th century, and may even be associated with some of Leonardo's drawings. The author traces its history from the 16th century and attempts to show the relationship between the complex geometric theory and its embodiment in metal. The interests of 17th and 18th century mathematicians seems to have arisen from a desire to increase the speed and efficiency of the gears in mills, where, although the speeds were low, the load was substantial. Precision craftsmen such as clock and astronomical instrument makers seem to have accepted empirical solutions for the form of their gear teeth, probably because their gears operated at low speeds under small loads, and, in the case of clock makers, the gears ran in only one direction and backlash did not have to be considered. Precise solutions to gear teeth problems were sought and found in the design of production machinery after 1800. The higher speeds and greater complexity of machinery during the 19th century and after, were made possible by the fact that the gear cutting machine had become a production tool.
This is the first of a series of monographs intended to form the basis of a history of tools.

Contents:- The Mathematics of gears—The Geometers — The translators — The scientific mechanics — The clock and instrument makers — The first gear cutting machines — The instrument makers — Production gear cutting machines — Types of gear cutting machines — The first production machines, 1800 - 1850 — Evolution of the production machine, 1850 - 1910 (Formed cutter types; Template types; Describing generating types; Moulding generating types; Hobbing types; Impression types). — Automatic gear cutting machines, 1875 - 1910 — Precision gear grinding and gear measurement — Conclusion — Bibliography.

Woodbury, Robert S. **"History of the Grinding Machine: a historical study in tools and precision production."** *Cambridge, Massachusetts, Massachusetts Institute of Technology, Technology Press,* 1959. 191 *pages. Illustrated. Diagrams.* (Technology Monographs. Historical Series, No. 2.)

The grinding machine is one of the most recent of the machines to come into industry, but the grinding process to shape materials to men's needs is one of the earliest we know. In his introduction the author orientates the reader by surveying the history of grinding from the Neolithic (Stone Age) period (15,000 - 5,000 B.C.), but in his monograph he ignores the use of grinding as a method of working materials other than metals, and begins his history at the time the process was first mechanised, probably in the 9th century of our era. He devotes most space to late developments during the 19th century and afterwards. He considers grinding as a metal-working process to be of great industrial significance, and he attempts to indicate the historical influence of a given tool on the industrial production it makes technically possible. Later monographs will deal in the same way with the history of high-production automatic machine tools. The book is well illustrated by photographs and diagrams. The technological growth of the grinding machine is illustrated graphically on the endpapers, where the changes in the machine itself and in the size and proportion of the grinding wheel used on it, are co-ordinated with the resulting improvements in precision and cutting capacity.

This is the second of a series of monographs intended to form a basis for the writing of a history of tools, the first being a History of the Gear Cutting Machine.

Contents:- Introduction—Early mechanisation of grinding, 850 - 1830 A.D. — The beginnings of the industrial grinding machine, 1830 - 1860 — The grinding machine comes of age. Beginnings of precision grinding, 1960 - 1905 — The grinding wheel. Transition from natural abrasives to the artificial wheel, 1820 - 1910 — Charles H. Norton. Heavy production grinding, 1890 - 1920 — Specialised grinding wheels meet the demands of industry, 1895 - 1930 — High speed production grinding, Automatic and Centreless — Modern grinding wheels and surface finish, 1910 - 1950 — The science of grinding, 1900 - 1950 — Conclusion.

Worth, T. B. **"The Technological University of Delft, Holland."** *Birmingham, College of Advanced Technology, Department of Engineering Production,* 1959. 5 *pages.* Mimeo

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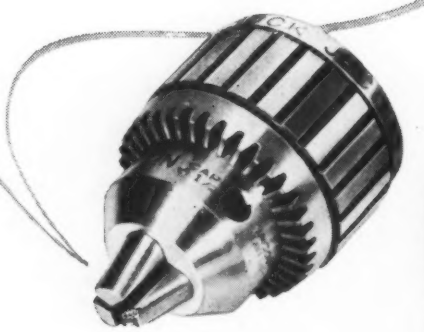

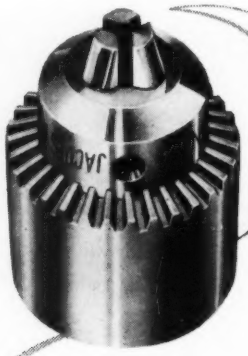

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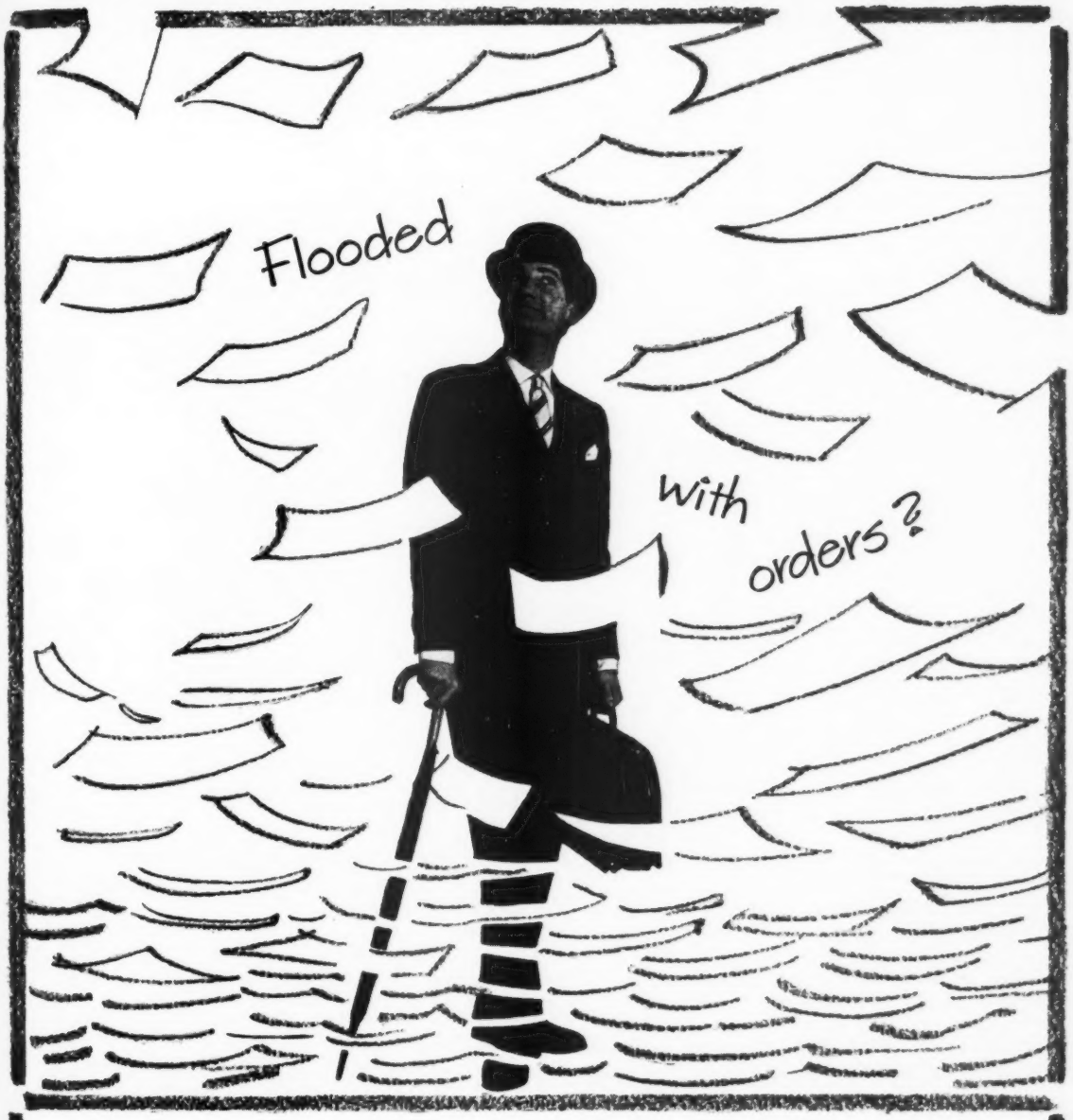

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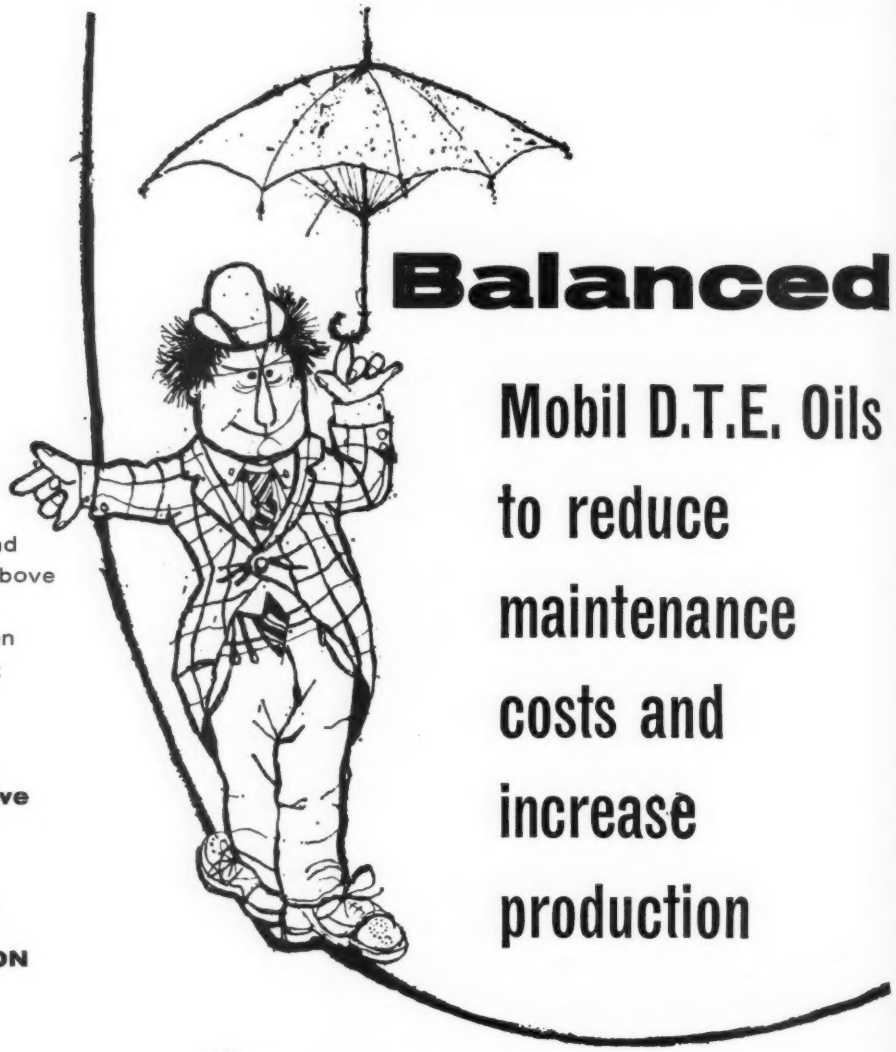

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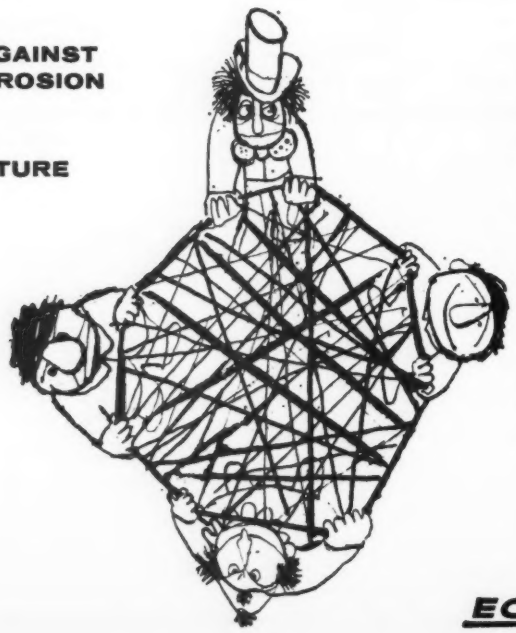

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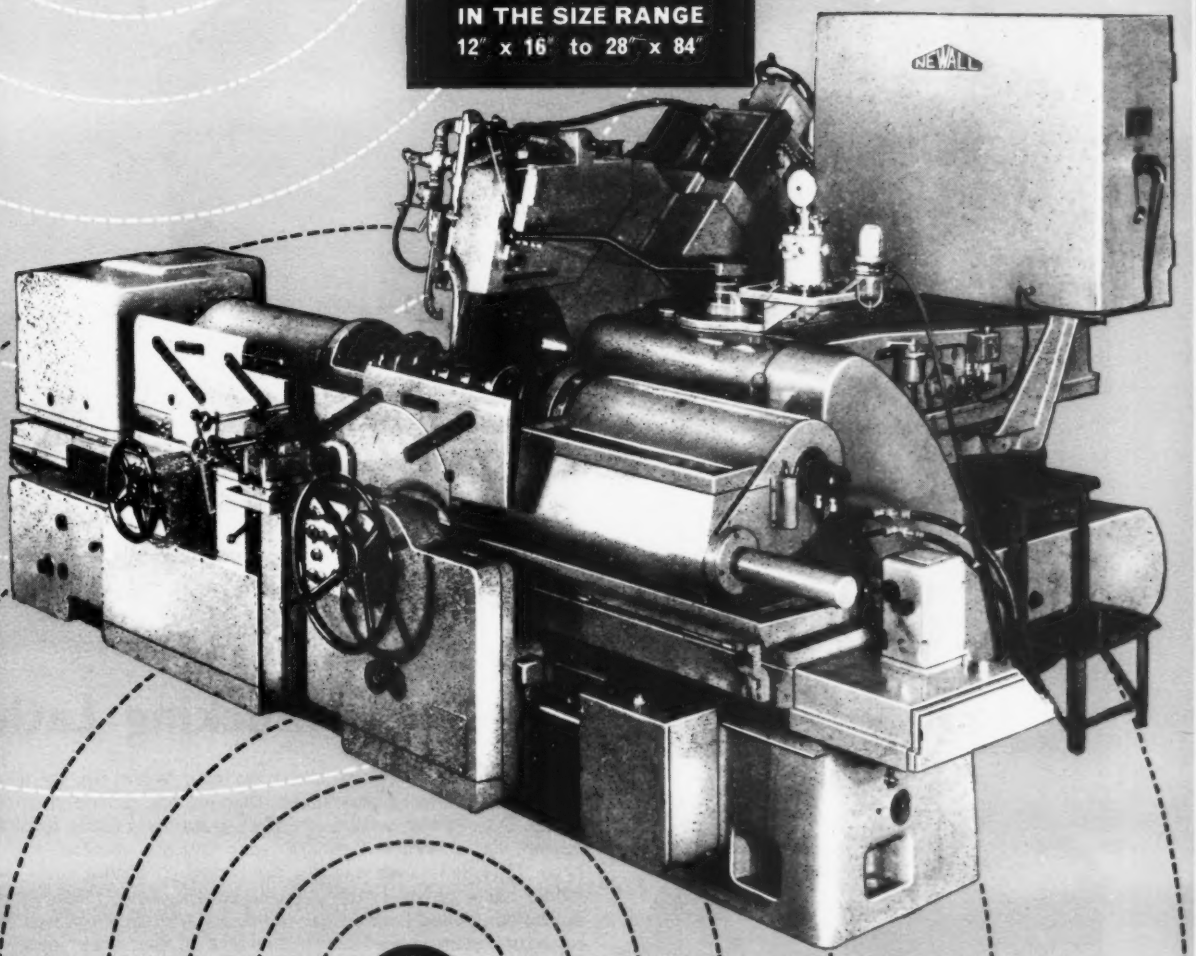

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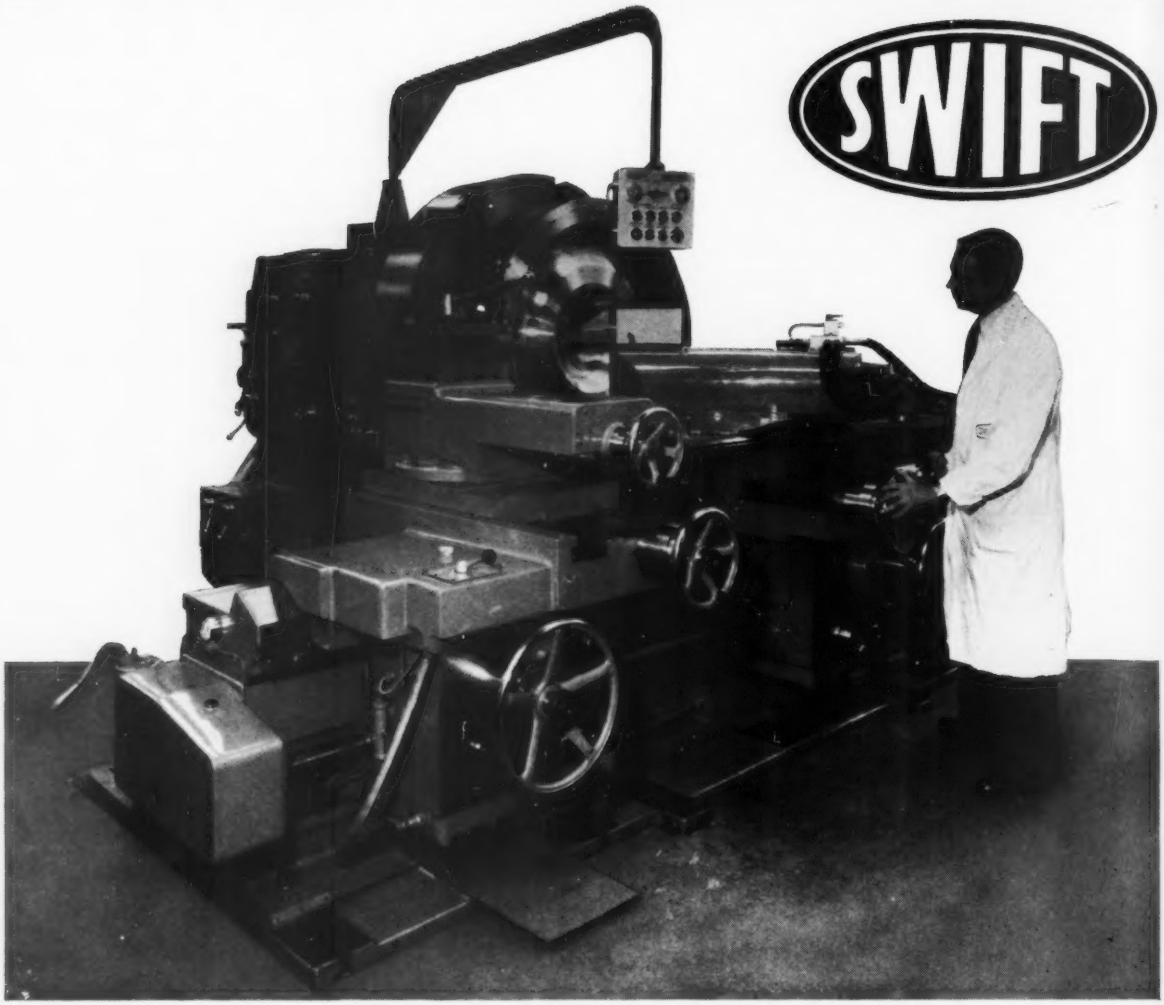
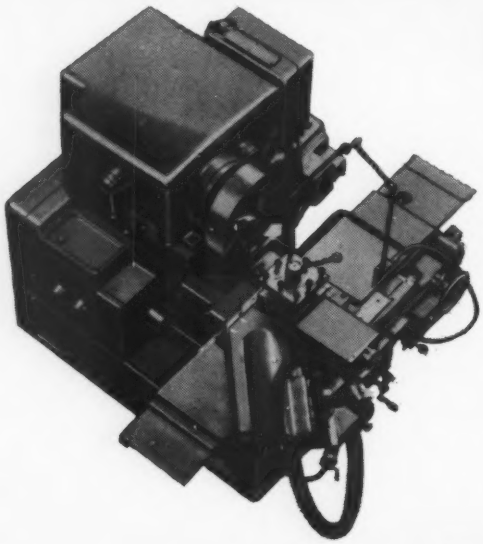
SWIFT





Right-Angle Chucking Lathes

The lathe shown above accommodates work up to 60 in. diameter. 18 Mechanical speed changes are provided and a 40 h.p. D.C. motor, with 6 : 1 infinitely variable range provides power via a Ward Leonard set. Overall spindle speeds, 1 to 120 r.p.m. Two saddles are fitted and the right-hand saddle has a swivel type hydraulic copying unit. Motor speed can be controlled from either saddle by selector switch to give constant cutting speed across the face of the workpiece.

Other Right Angle Chucking Lathes are available as shown on the left in a range of sizes for maximum diameters of 24 in., 36 in. or 48 in. Hydraulic copying is a standard feature of these lathes.

GEORGE SWIFT & SONS LTD.

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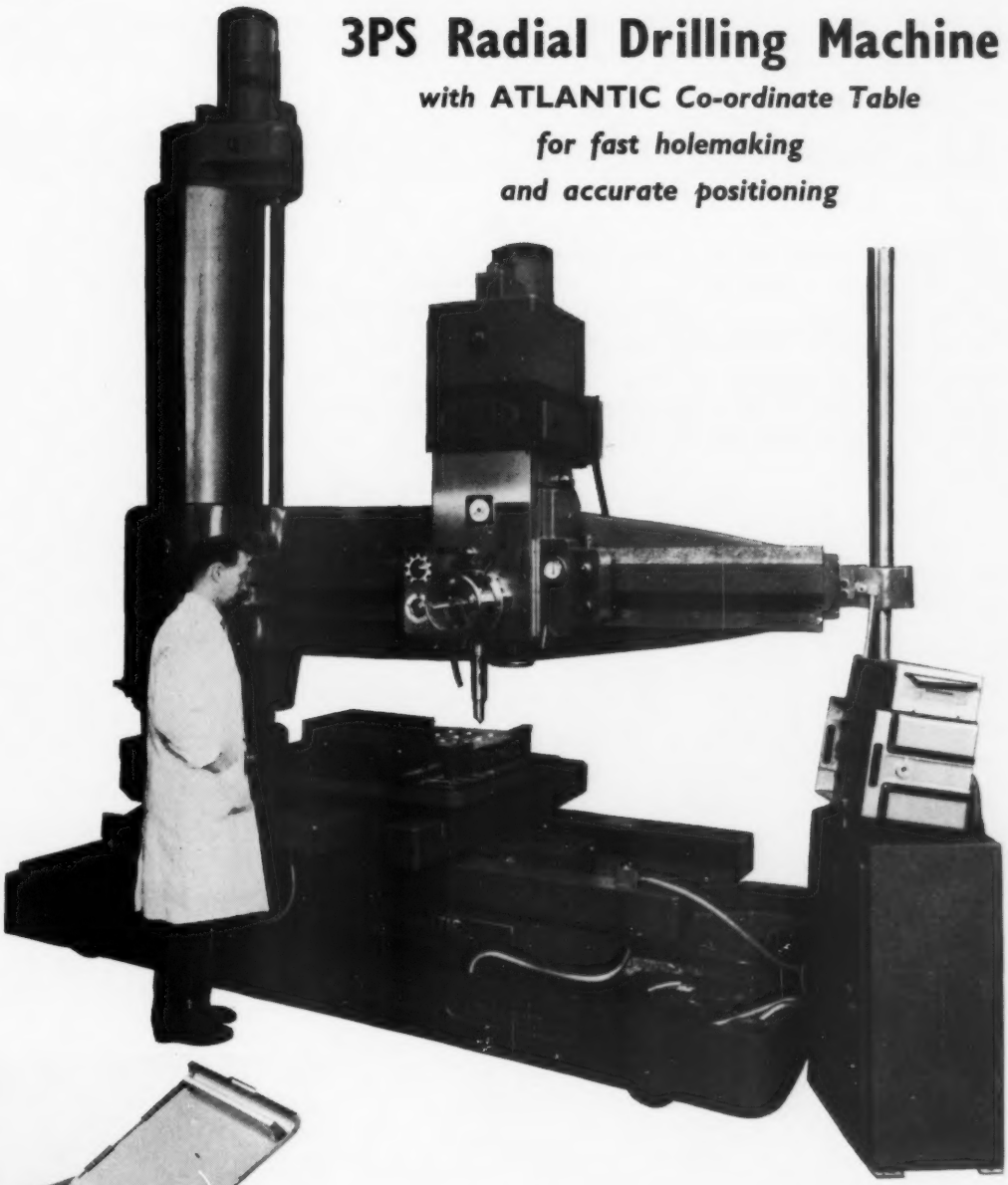
5449

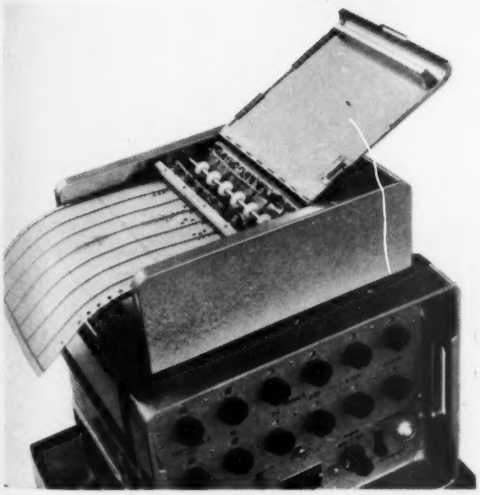
3PS Radial Drilling Machine

with ATLANTIC Co-ordinate Table

for fast holemaking

and accurate positioning





The Asquith Type 3PS Radial Drilling Machine with pre-selection to speeds and feeds can be used to advantage for programme-controlled drilling or boring operations utilising the Atlantic table, as illustrated, to provide positional accuracy. The close-up view on the left shows the control panel of his table set-up for punched card selection of drilling positions.

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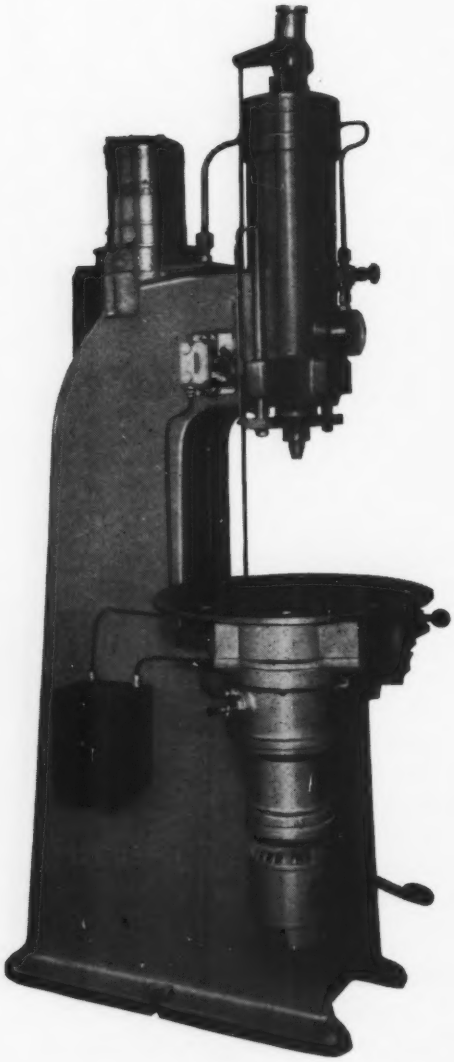
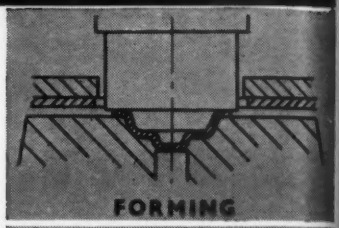
A442

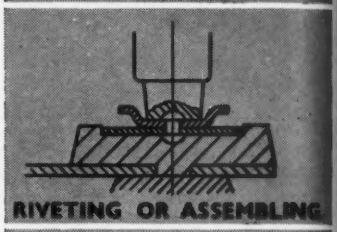
The hydraulic press for high-output

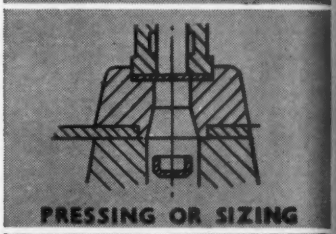
The illustration shows a 12 ton Hi-Ton hydraulic press equipped with the standard Hi-Ton electro mechanical indexing table which is arranged with eight indexing stations. The table rotation is controlled by the return stroke of the press and the whole unit can operate on a continuous automatic cycle.

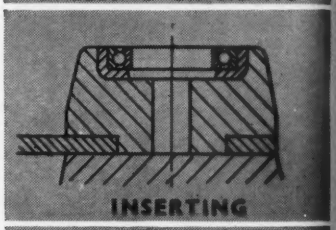
The Hi-Ton hydraulic press can be pre-set to operate at any required pressure from zero to maximum of the press — a feature which ensures maximum tool life and therefore still further gains in output.

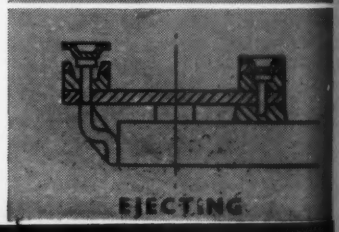












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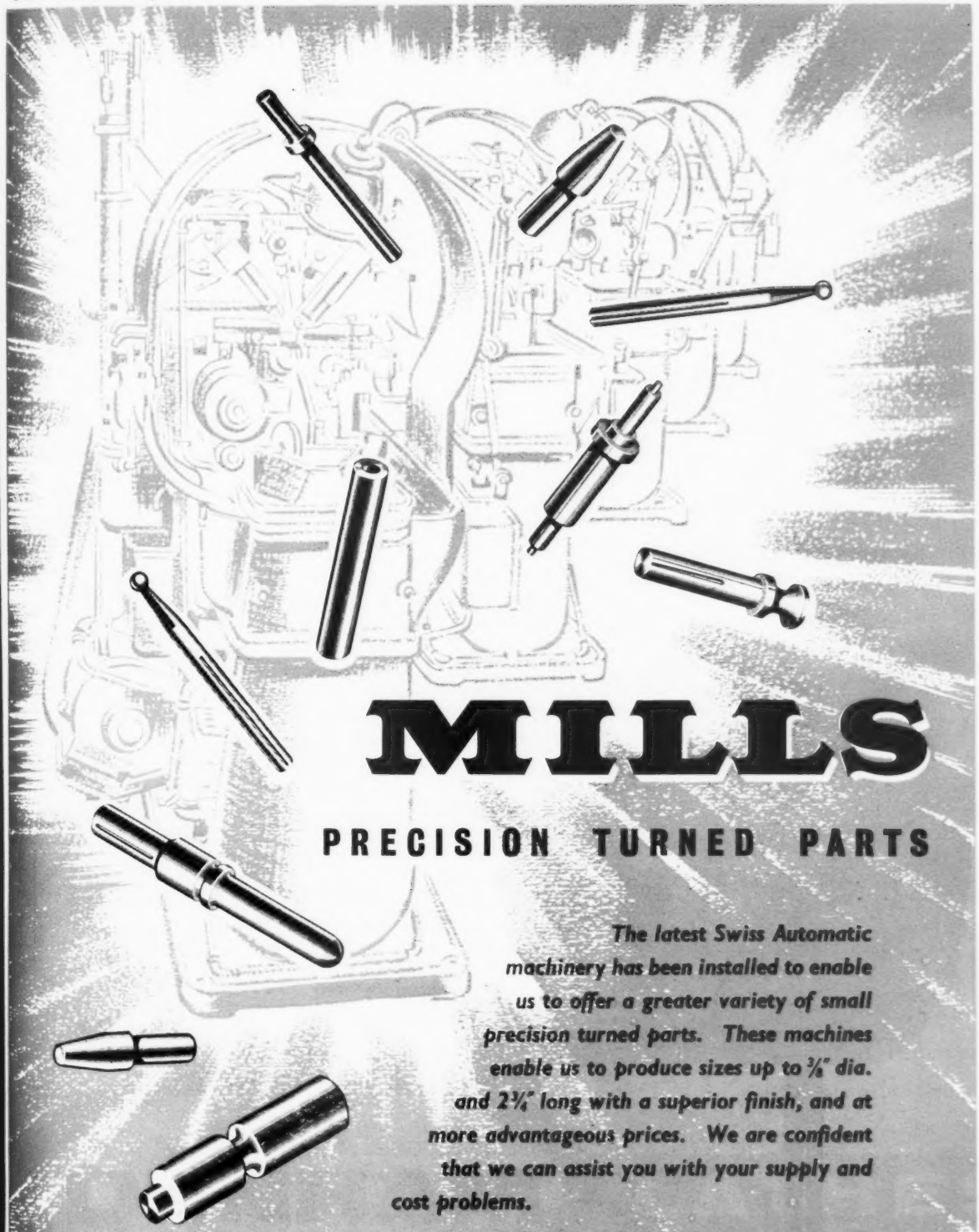

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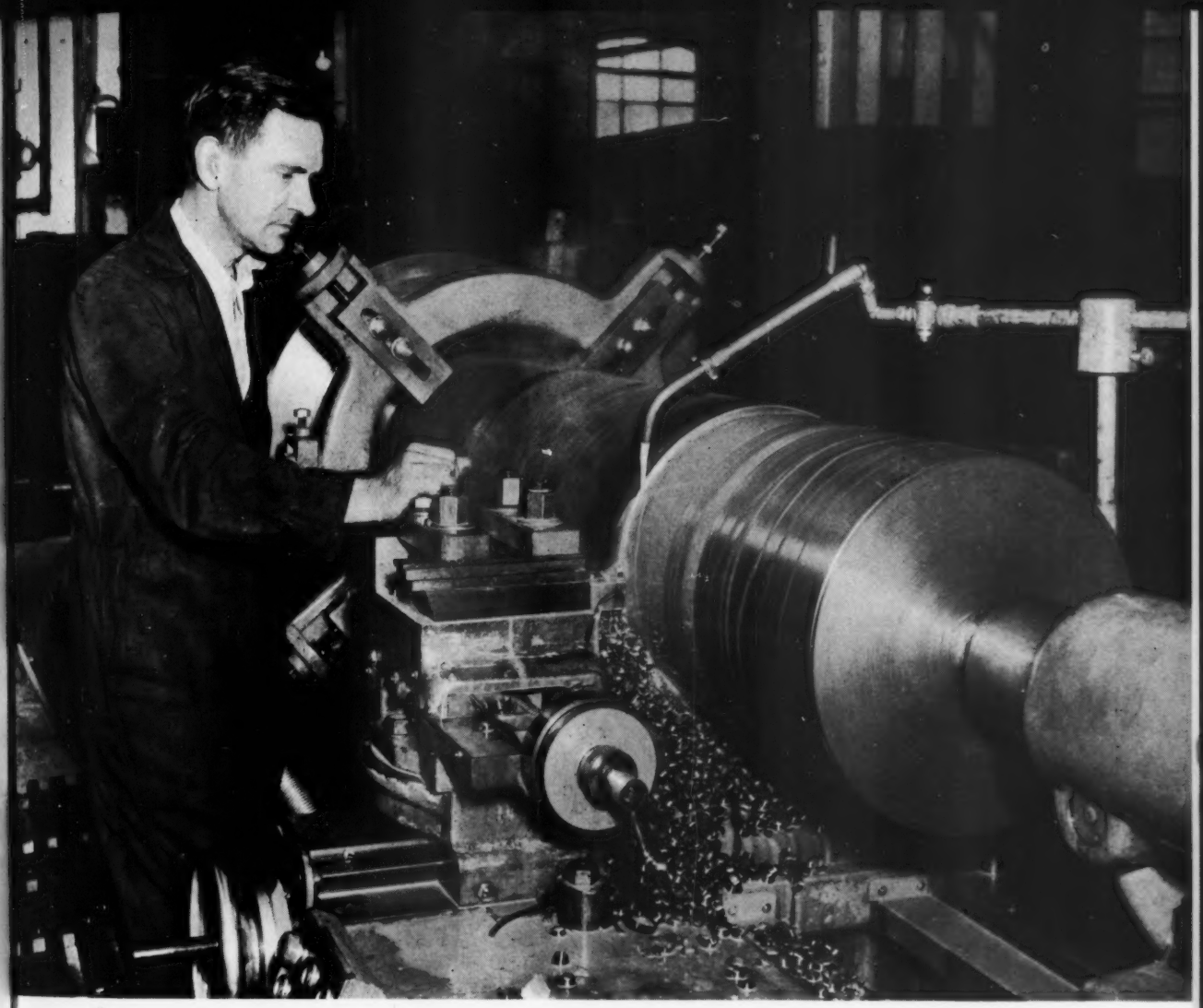

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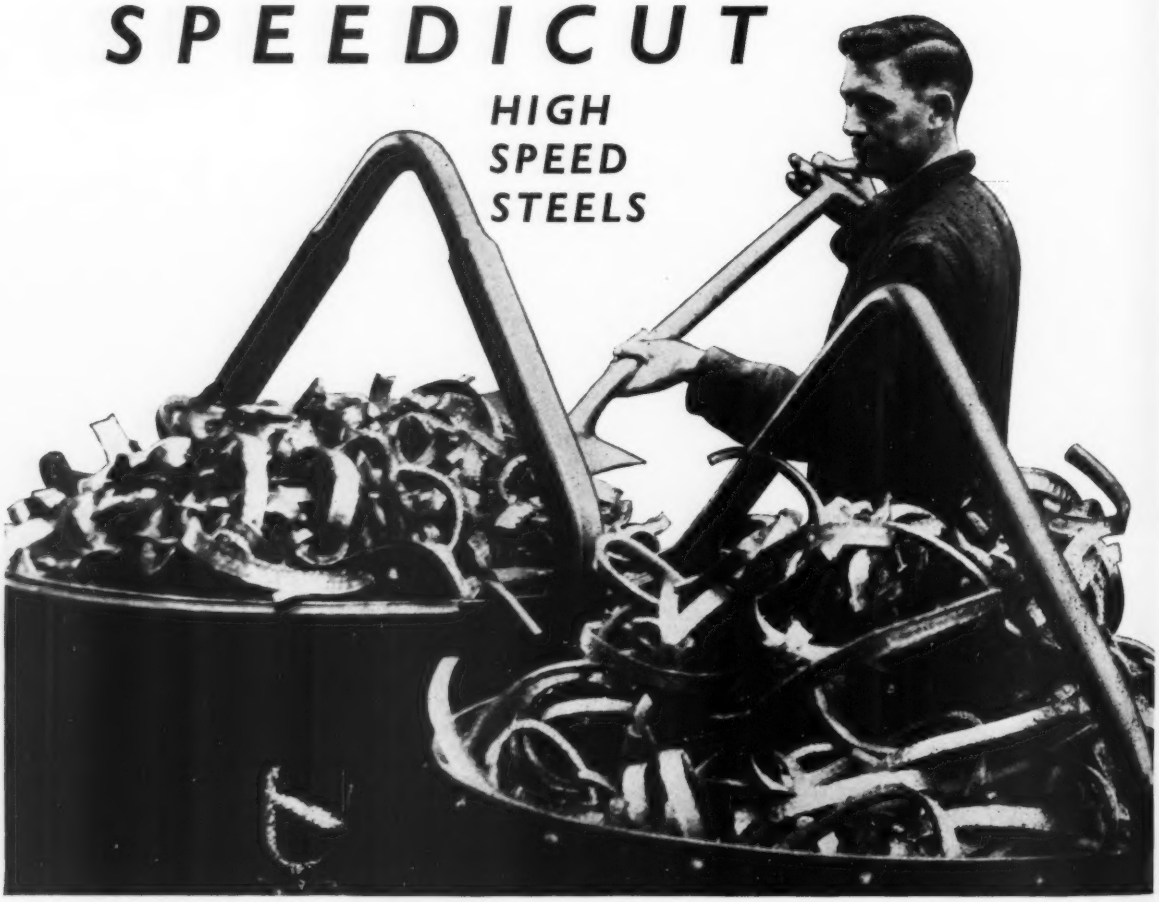

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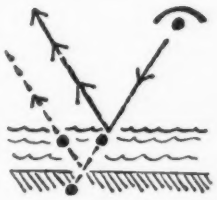
Electrical Aids in Industry *Data Sheet* **No. 13**

Infra-Red Heating

Infra-red heating is the name given to the method of using in industrial processes radiant heat from heaters specifically designed for that purpose. This differentiates it from methods employing both radiation and convection, as in furnaces, although the effect of the radiation is much the same in both cases.

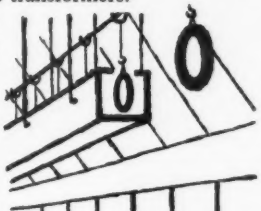
Radiant heat provides a higher rate of heat transfer to bodies not highly reflective than does convection, unless high-velocity forced convection is used. The rate of heating of a body depends upon the intensity of radiation on its surface, the proportion absorbed by the surface and, subsequently, on heat conduction. In heating very thin bodies, for example paint films, the radiation not reflected nor absorbed passes through and is in turn reflected or absorbed by the underlying material. This reflected heat is partly absorbed by the paint film "on the way back". Despite this effect it is an exaggeration to claim that infra-red "heats from the inside out" and it remains largely a surface heating effect except in a few special cases.



Infra-red heaters mainly use metal-sheathed elements in special reflectors, but infra-red lamps with internal reflectors are still used in special cases. Other types use silica-sheathed elements or quartz-sheathed lamps in reflectors. A wide range of heaters is available with simple mounting arrangements to enable heat to be applied quickly and effectively either in a production line or in some odd corner.

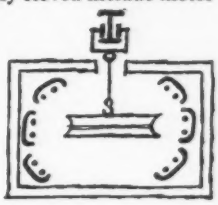
Control of the charge temperature is effected by regulating the heating time and power. In the case of a moving charge, this is done by adjusting the conveyor speed and the number of heaters in circuit, i.e., by adjusting the effective length of the oven. Some of the heaters may be controlled by energy regulators or adjustable transformers.

The advantages of infra-red heating over convection heating include reduced heating times, reduced floor space, lower installation costs, almost instant starting, ability to focus the heat, and flexibility in effective oven length. Infra-red ovens can often be mounted in the roof, saving valuable floor space. Infra-red heating is not generally favourable for heating large bodies of low heat conductivity.



Paint Stoving

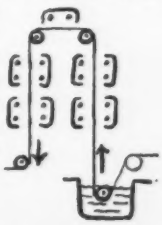
Not all paints are suited to infra-red radiation, but suitable paints are stoved quickly and often give a better finish. Synthetic enamels are the most suitable. Articles successfully stoved include motor car bodies, wheels and other accessories, refrigerator and washing machine cabinets, cylindrical drums and barrels, metal furniture, valve hand wheels, metal toys and a host of other articles. Lacquers and varnishes are being quickly and effectively stoved on jewellery, packing strips, tubes, films and similar products. Special infra-red lamp ovens stove synthetic finishes on wooden furniture and components. In all cases stoving times have been reduced very considerably.



Moisture Extraction

Sheathed element heaters are particularly useful for drying surface water films, their radiation being readily absorbed by water. High rates of drying are possible provided the water vapour can readily disperse. Drying of "contained" water can be effected provided the water can diffuse from the interior at a rate equalling the surface drying rate. With heat-sensitive materials sheathed element heaters may have to be arranged to move away from the material to avoid overheating if the conveyor stops, being interlocked with the conveyor for this purpose. Lamps are sometimes used instead for such materials because of their instantaneous cut-off.

Infra-red is widely used for drying coatings and inks on paper and textile products, bottle seals and labels, clayware and glazes, pigments on leather and many other products.



Plastic Heating

Infra-red heating is widely used in the plastics and allied industries. Typical applications are the preheating of plastic pellets and of sheets prior to moulding, curing of plastic and rubber sheets and belts, heat setting of nylon and similar fabrics, drying and curing of latex films on carpets and many others where a plastic forms the whole or part of the product.

The above are just a few examples of successful applications of infra-red. In many other processes infra-red heaters can often be fitted quickly and cheaply, to save time, labour and floor space and, therefore, money.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London W.C.2. Telephone: TEMple Bar 9434.

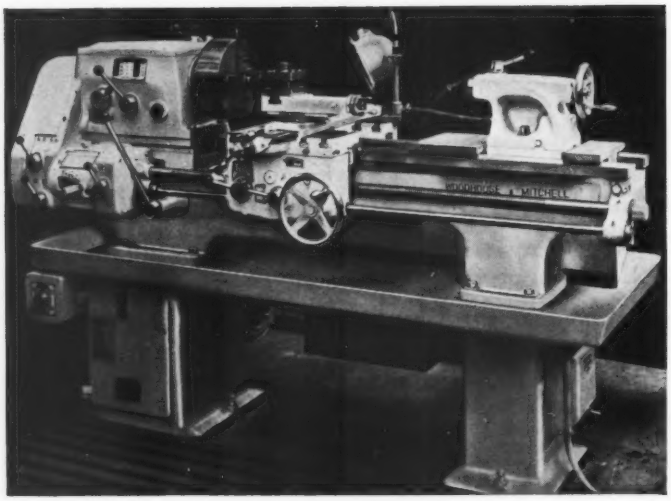
Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available — "Resistance Heating" is an example; "Induction and Dielectric Heating" is another.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

8191

CUT HERE

WM LATHES AT B·O·A·C



In their maintenance shop at London Airport B.O.A.C. have a number of W.M. Lathes, both series 85 and 70 Junior. These are engaged on high grade precision work, and it is due to the most satisfactory experience of these tools in production that B.O.A.C. have periodically added to their complement of W.M. Machines.

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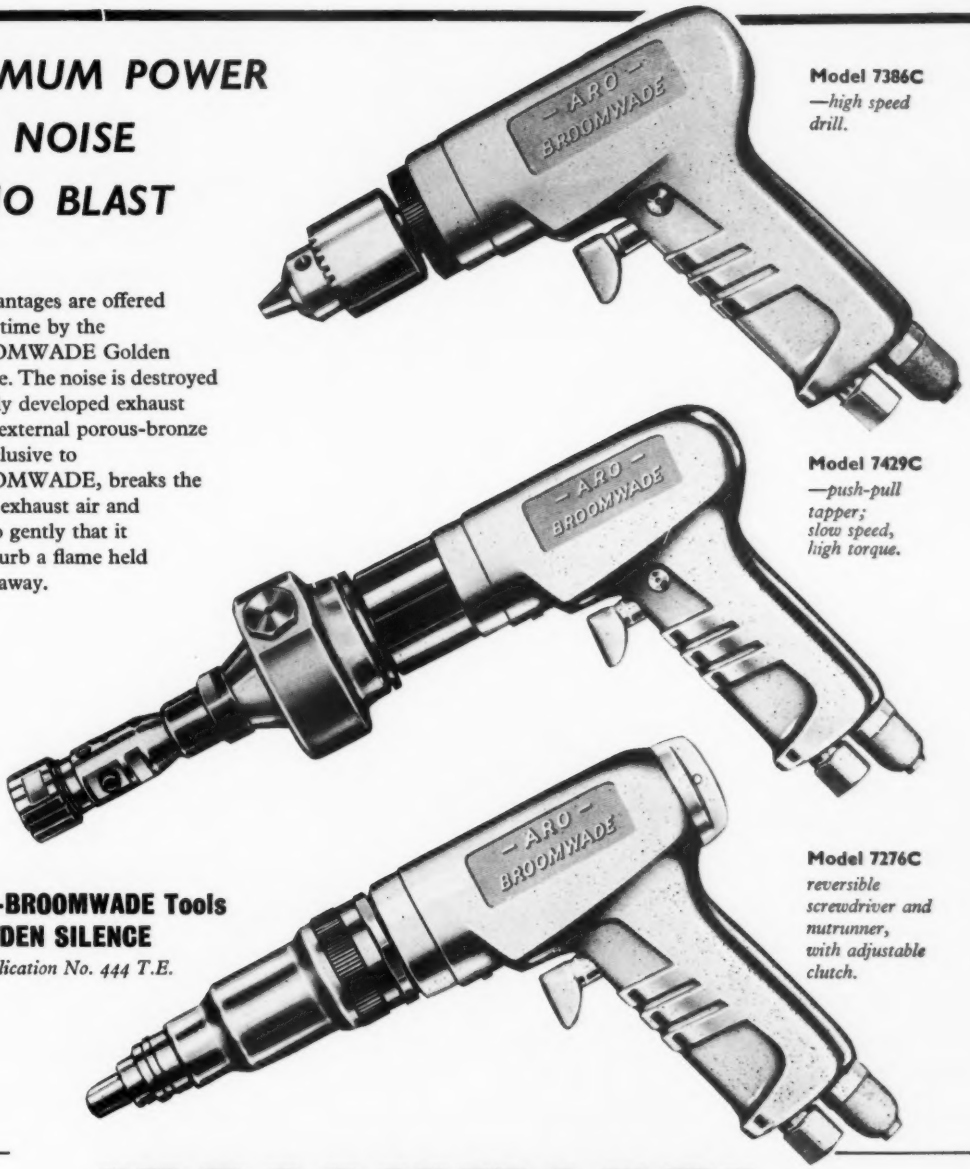

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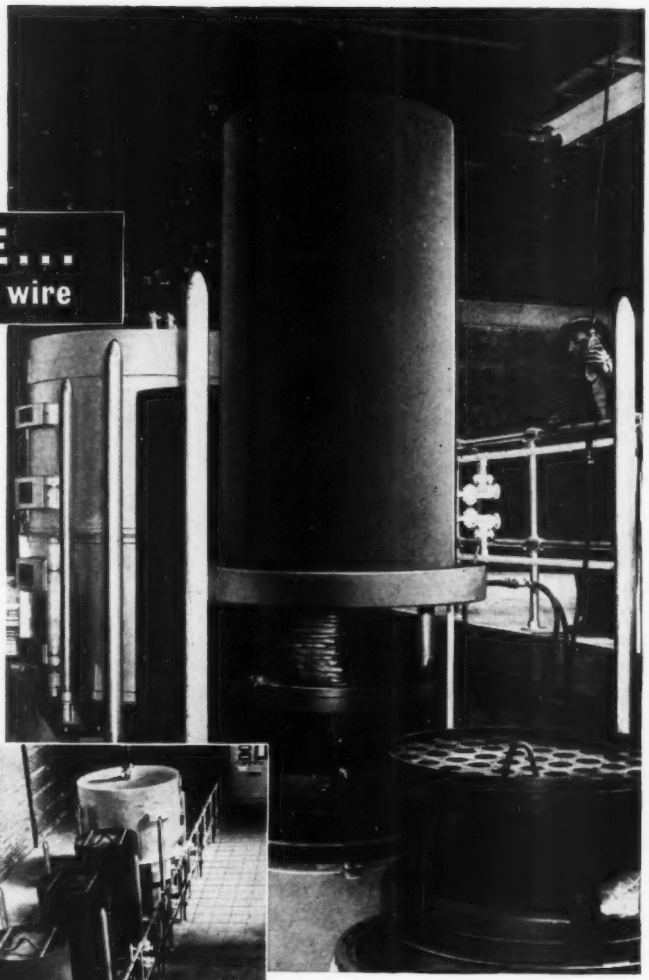

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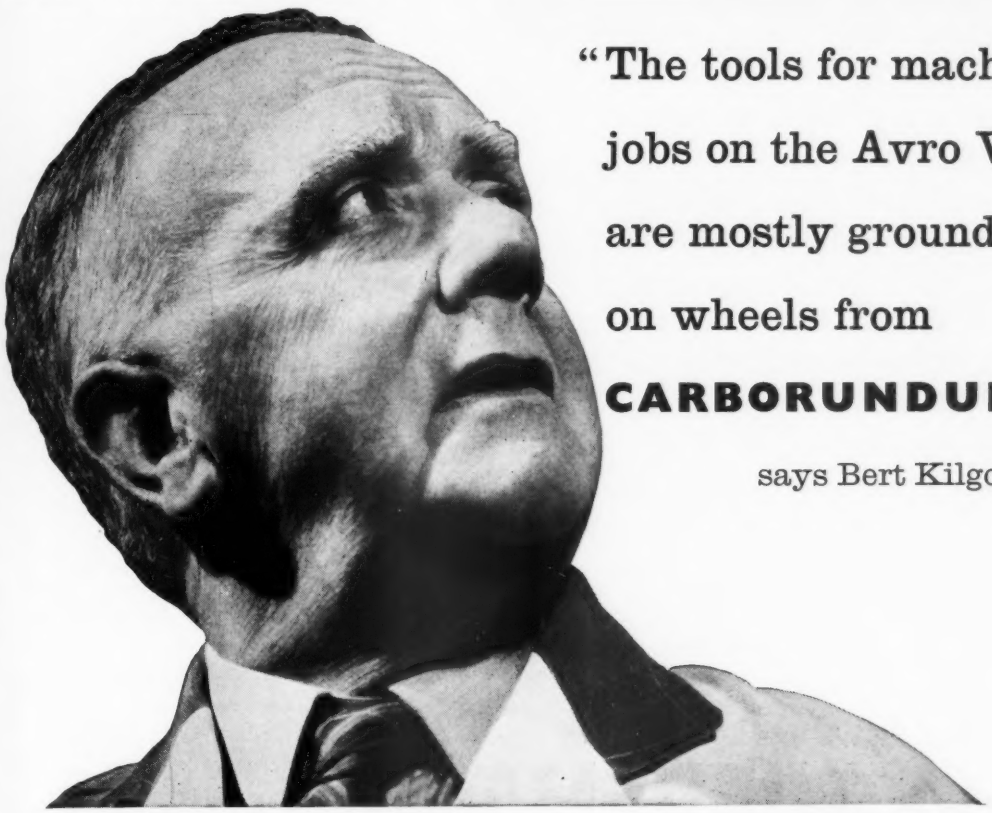
Bert Kilgour has worked at the main factory of A. V. Roe & Co. Ltd, at Chadderton, for 40 years, and is now the senior foreman of the toolroom, in which 300 men are employed: "Must be one of the biggest toolrooms in the country," Bert says. "We started getting grinding wheels from CARBORUNDUM in 1936, and they've supplied most of our wheels ever since then. That's for the whole factory — not just the toolroom. Why? Well, because their wheels do a good job, and give us good service. They've always been ready to help us when we've asked them to."



"The tools for machining jobs on the Avro Vulcan are mostly ground on wheels from CARBORUNDUM"

says Bert Kilgour

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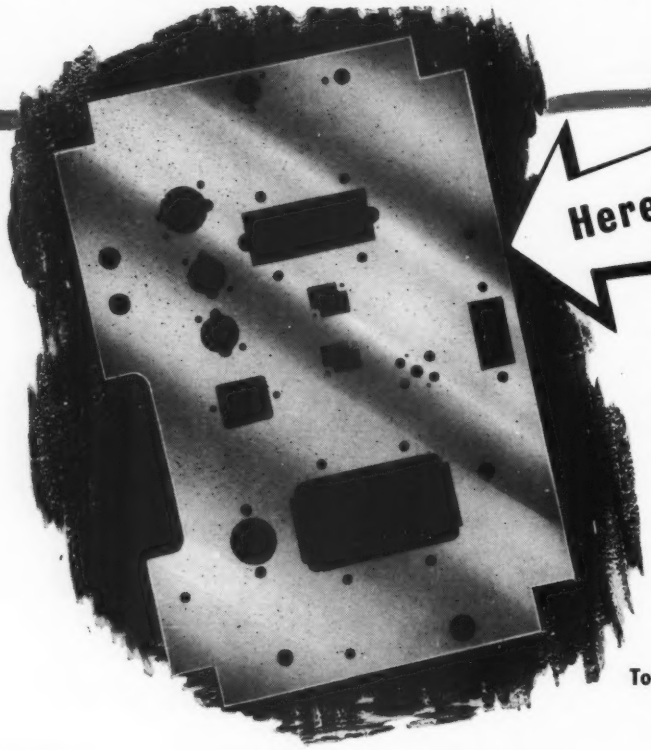

Here's one example

18" x 12" x 16 S.W.G. Mild Steel Plate

	Time (secs.)
63 openings $\frac{1}{8}$" to $1\frac{3}{8}$" diameter plus slots, corners and rectangles up to $4\frac{3}{4}$" x $2\frac{3}{4}$" ...	189
Rotate turret 14 times	28
Unload blank	8
Total	225 secs.

Total floor-to-floor time 3 min. 45 secs. each

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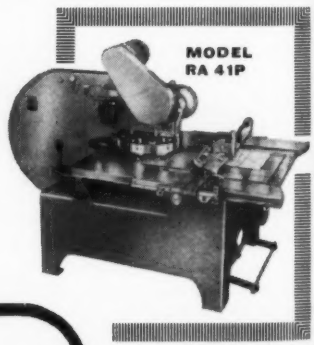

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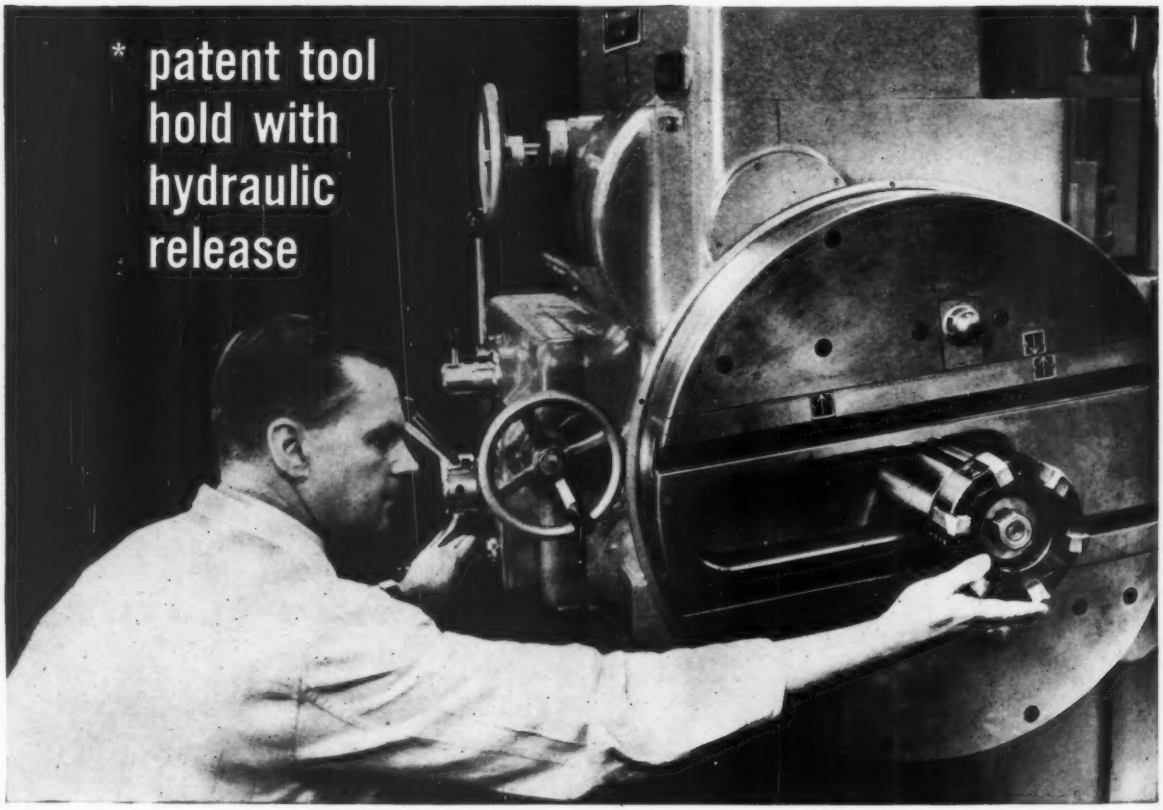

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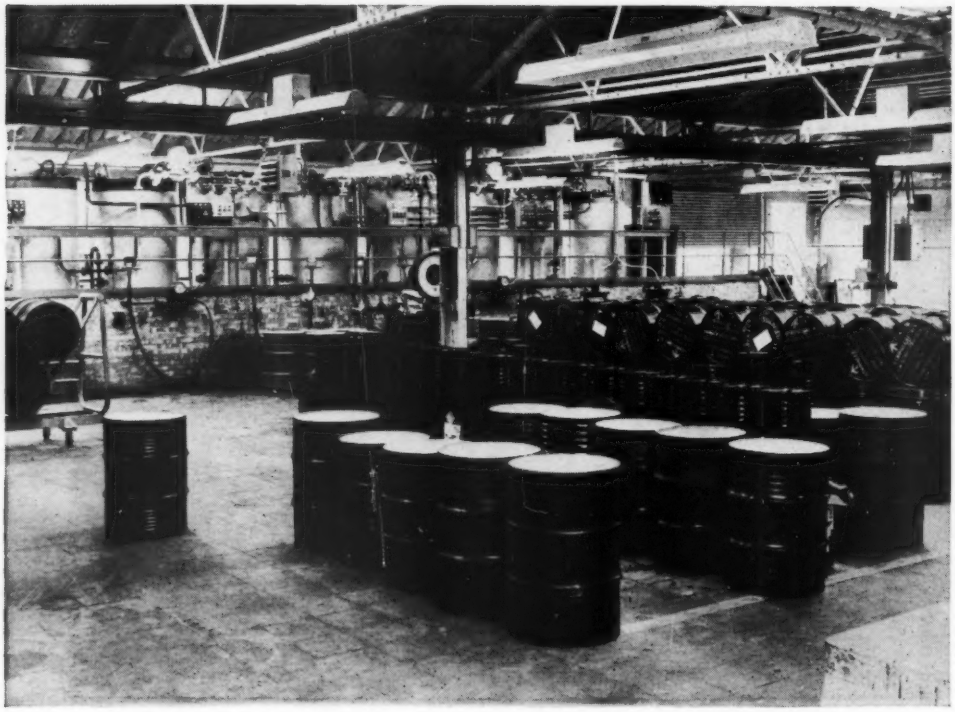

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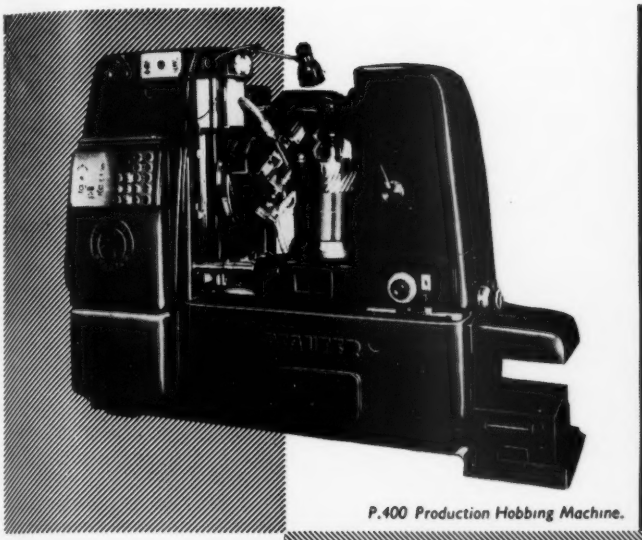
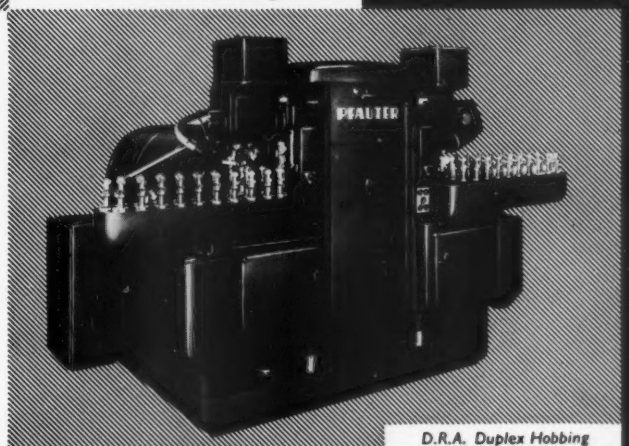


P.400 Production Hobbing Machine.

Original PFAUTER Hobbers

Pfauter hobbing, combining these three techniques Climb cutting, Ultra hobbing, Exclusive diagonal cutting gives fastest hobbing times ever with precision, fine flank finish and extended hob life.



D.R.A. Duplex Hobbing Machine with conveyor loading

ORIGINAL PFAUTER

P.160 Horizontal Hobbing Machine with magazine loading.

MANUFACTURING PROGRAMME

Vertical Work Mounting

Model	Max. Gear dia. in.	Max. Gear width in.	Max. D.P.
RS00	10/6	6½	17/10
P250	10/8	7½	10/7
P251	10	8½	6
DRA duplex	10	8	3
P400	16	11½	4
P630	25	16½	3
RSIV	30	11½	3
P900	35	20	3
P1250	49	24	2
RS3V	72/47	23	2½/1¾
P1800	72	30	1½
P2500/3000	100/120	30/40	1½

Horizontal Work Mounting

P160	6¼	15½	6
RS9K	11½	28½	2½

Worm and Thread Milling Machine

SF1	11½	28¾	1½

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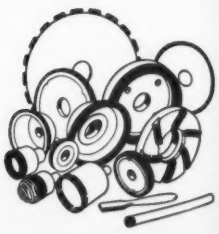
NBP 4084

for perfection in diamond wheels



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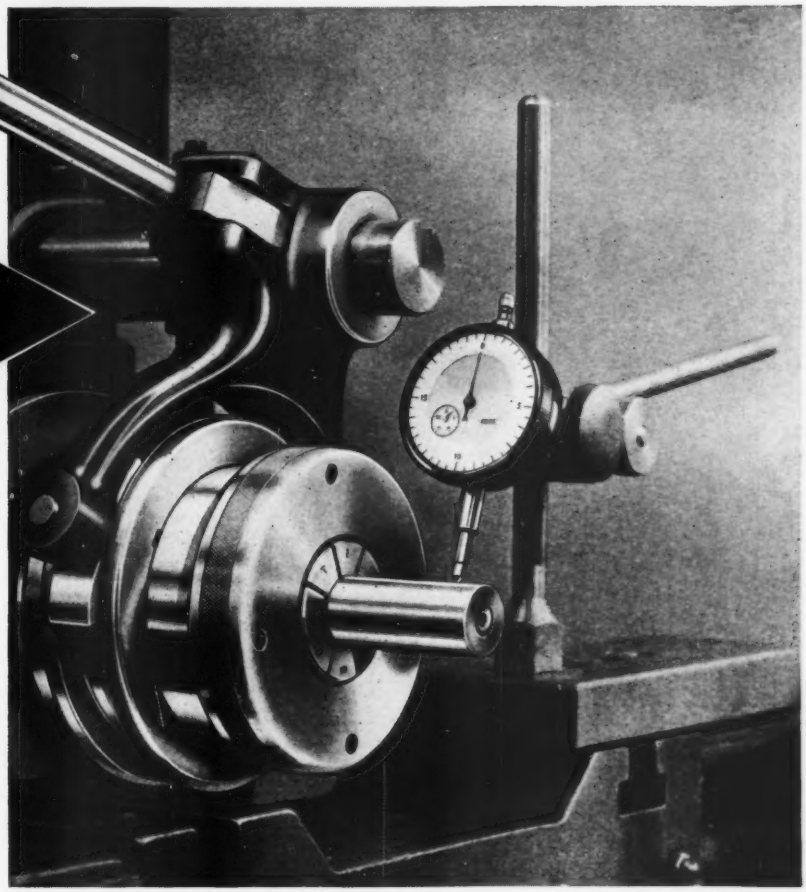
DISTRIBUTED BY **UNIVERSAL GRINDING WHEEL COMPANY LIMITED · STAFFORD**

CRAWFORD RAPIDGRIP



NEW LEVER -OPERATED CHUCK

for use with Crawford Multibore Collets

This powerful new dead-length chuck is particularly suitable for bar and second operation work; fitted with a Crawford rear support stop it can hold exceptionally short pieces. It is designed for operating Crawford Multibore Collets with their ¼" size range. There's less operator fatigue, too, because Rapidgrip's simple, powerful rack and pinion gear is easier to operate than more direct lever systems of collet closing. Another special feature is the fixed front cap which ensures constant accuracy. An independent key allows easy bore adjustment.

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Witney · Oxon
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For welding the high-nickel alloys, as with other materials, there are special filler wires made to give the best results. *Don't spoil good material by using the wrong grades.*

MATERIAL	ARGON-ARC FILLER-WIRE
MONEL* *corrosion-resisting alloy*	60 MONEL
AT nickel	61 nickel
Low-Carbon AT nickel	61 nickel
DURANICKEL* *age-hardenable nickel*	61 nickel
K MONEL* *age-hardenable corrosion-resisting alloy*	64 K MONEL
NI-O-NEL* *corrosion-resisting alloy*	65 NI-O-NEL
CORRONEL* 210	CORRONEL 210
CORRONEL* 220	CORRONEL 210
CORRONEL* 230 *corrosion-resisting alloys*	CORRONEL 230

MATERIAL	ARGON-ARC FILLER-WIRE
INCONEL* *oxidation-resisting alloy*	NC-82
INCOLOY*	INCO-WELD 'A'*
INCOLOY* DS *heat-resisting alloys*	INCO-WELD 'A'*
NIMONIC* 75	NC-82
NIMONIC* 80A *high-temperature alloys*	NC-90
NIMONIC* 90	NC-90
BRIGHTRAY* 'B'	NC-82
BRIGHTRAY* 'C' *high-temperature electrical resistance alloys*	NC-82
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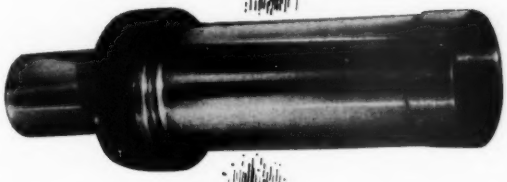
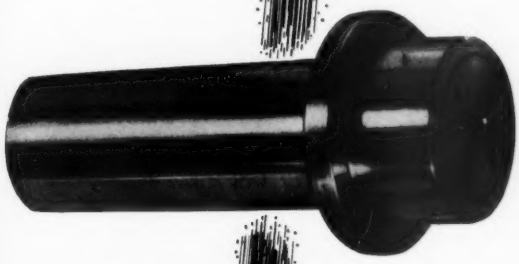
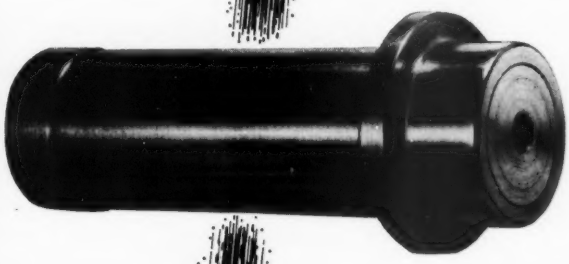


Perfection!



UNIBLAST



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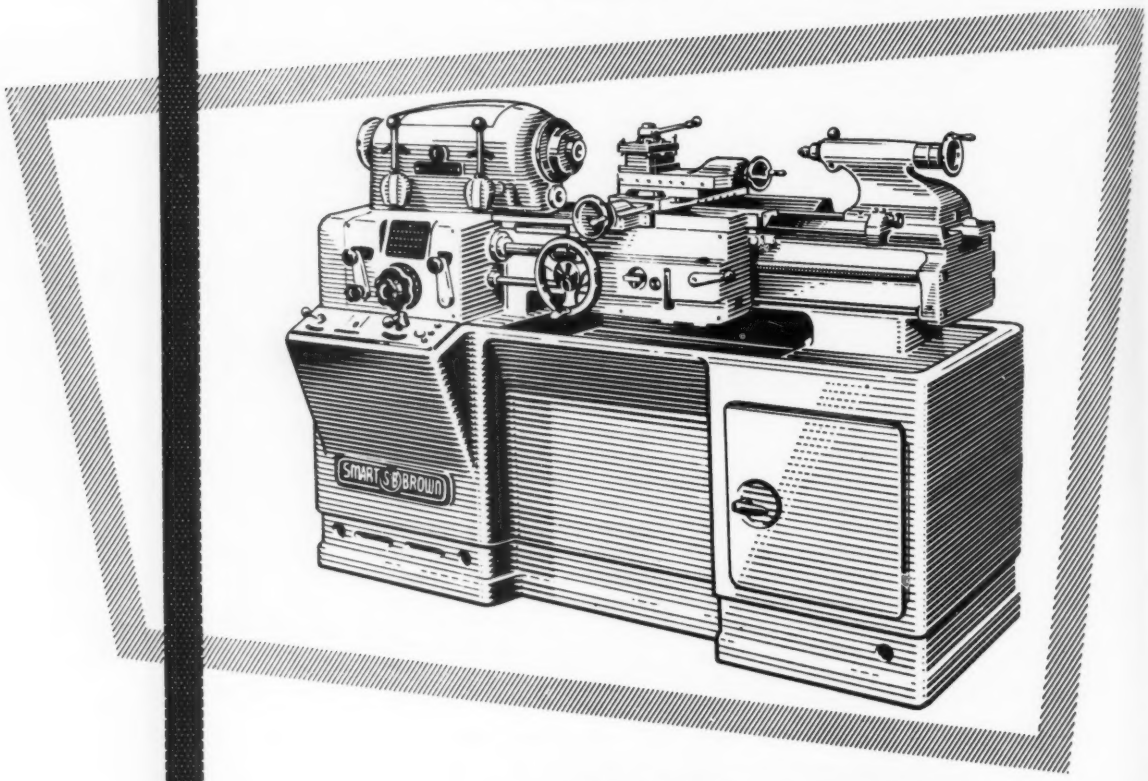
with flame hardened bed



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S.S./S.C. TOOLROOM LATHE

Distance between centres: 24". 1" Collet capacity

12 Spindle speeds available: 30 to 2500 r.p.m.

Threads: 4—112 t.p.i.

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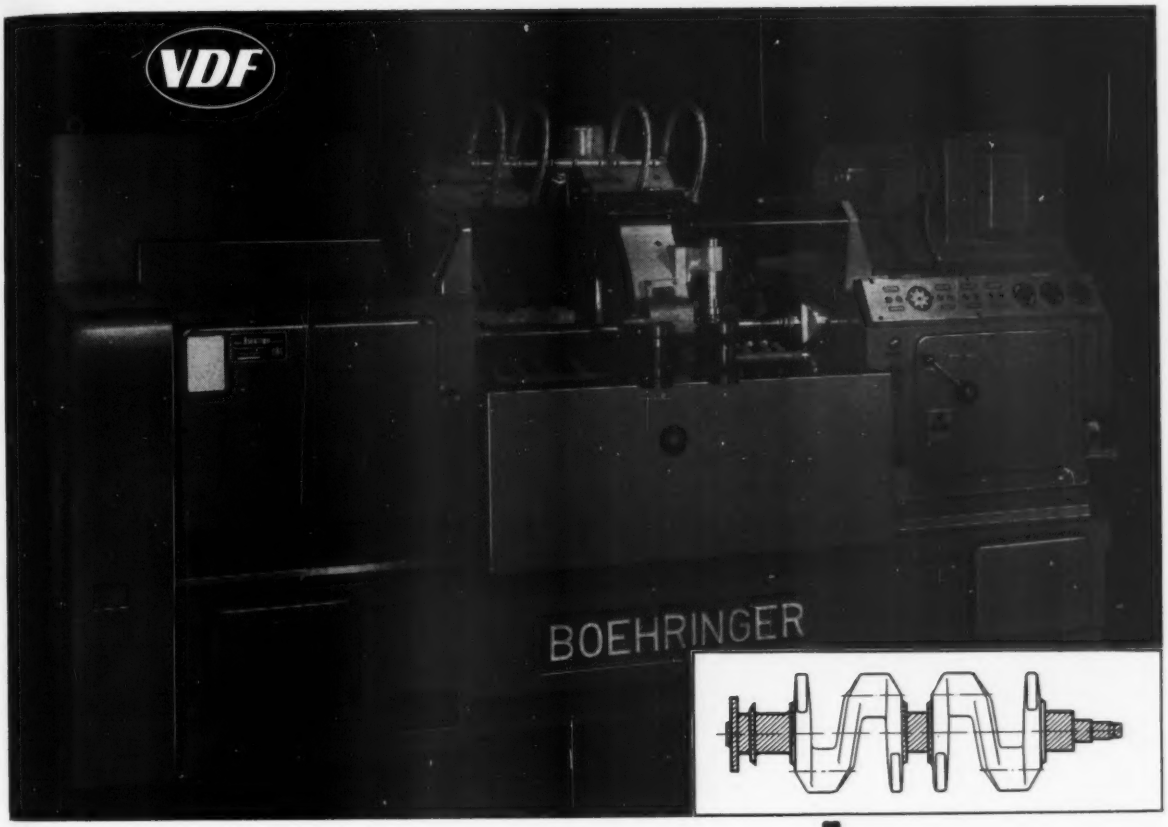

4-throw crankshaft, loaded and machined in 3.5 mins.

VDF Automatic Crankshaft LATHE

MODEL 1365

For the simultaneous machining of crankshaft end and intermediate journals and flanges.

- Fully automatic, interlocked cycle
- Simple work loading from centre chuck
- Tools readily accessible and easily changed
- Rapid tool approach and retraction
- Equipped with two facing slides and one swivelling slide
- Efficient chip disposal and coolant system

BRIEF SPECIFICATION

Crankshaft, max. length	31½ in.
Speed range r.p.m.	28-140
Feeds	.002-.016 in.
H.P.	33-45
Floor space approx.	140 x 70 in.

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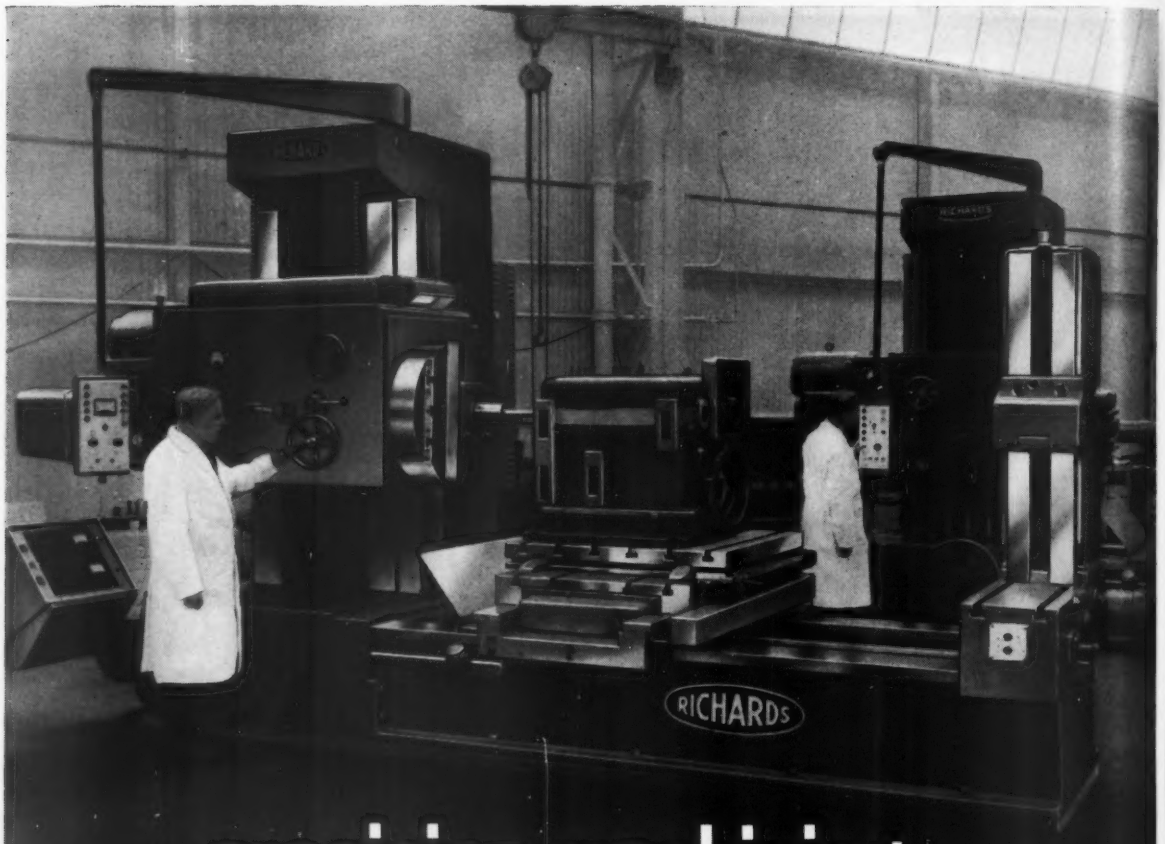

precision machining

with RICHARDS automatic co-ordinate positioning

THE MACHINES ILLUSTRATED ABOVE ARE REPRESENTATIVE OF A FULL RANGE WHICH INCLUDE TABLE, FLOOR OR PLANER TYPE HORIZONTAL BORING MACHINES

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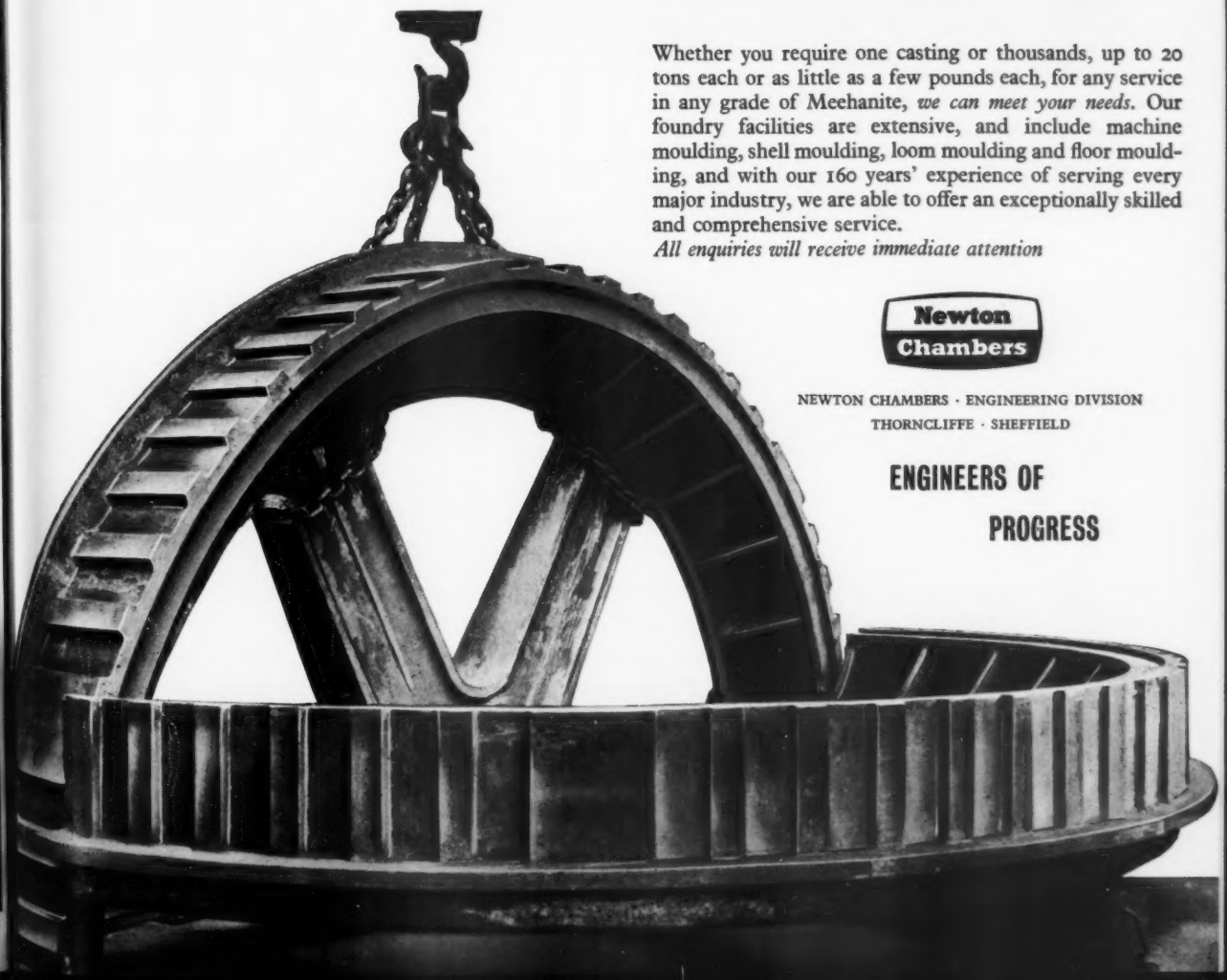

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Give You

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* LONG LIFE

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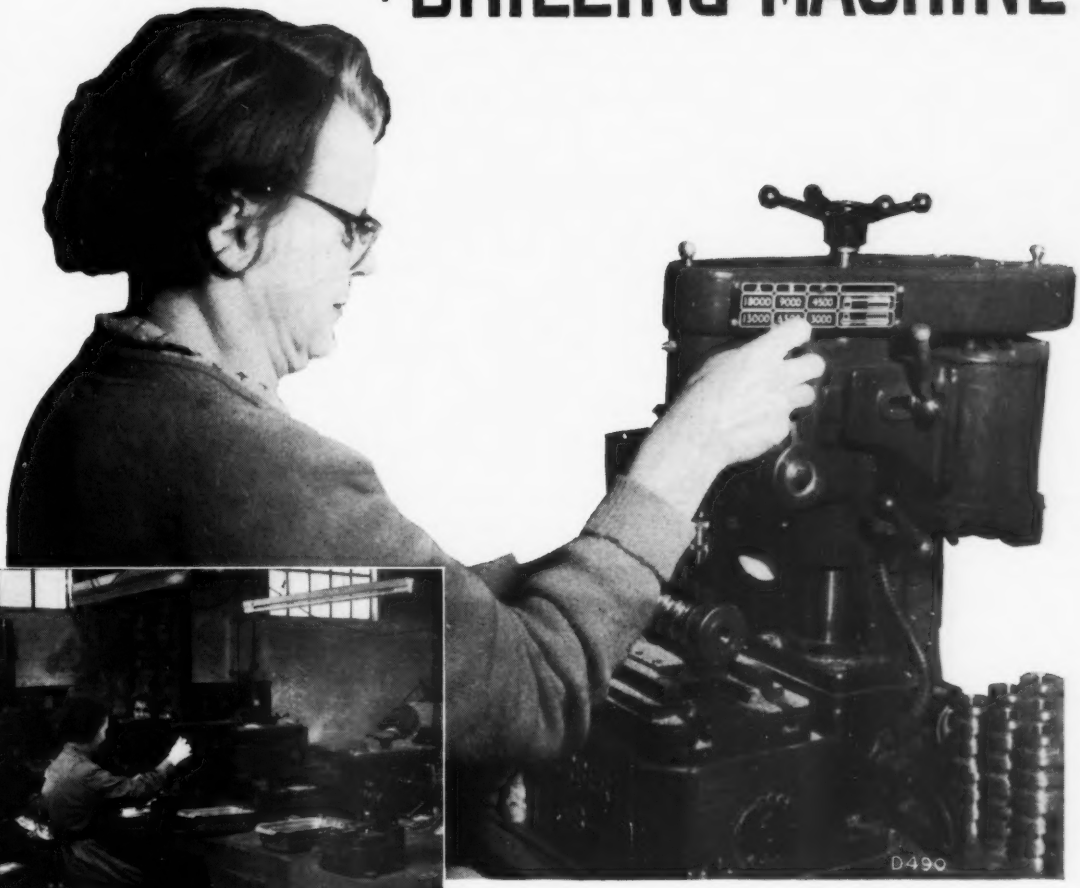
for drilling holes the human eye can hardly see, up to 1/8" diameter.

The HERBERT TYPE 'B' DRILLING MACHINE



Drilling four hundred and eighty 0.035" diameter holes around the periphery of two 1 3/16" diameter grooves in an air-control valve.

The Herbert Type "B" Drilling Machine is a bench-type single- or multi-column machine. Six speeds, maximum 18,000 r.p.m. Stroke 1⅝", radial capacity 4⅛".

Herbert Drilling Machines are made in ten types—single- or multi-spindle and turret—for drilling, tapping and associated operations, holes up to 1¼" diameter.

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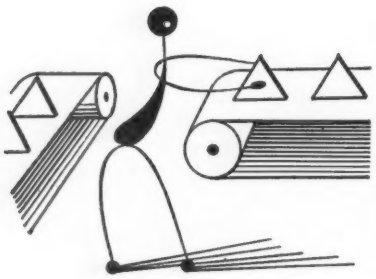
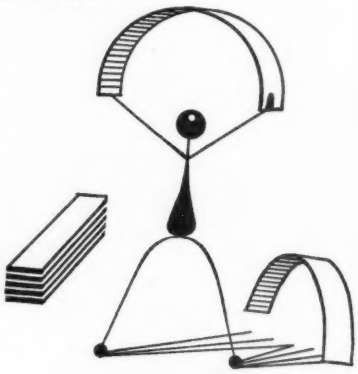
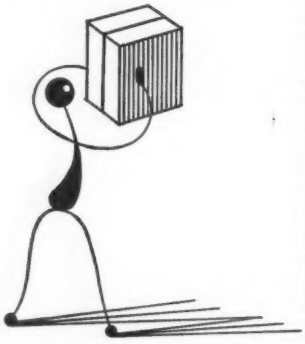


...transfer...

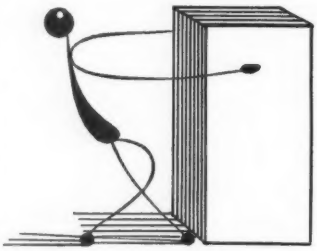
...open...



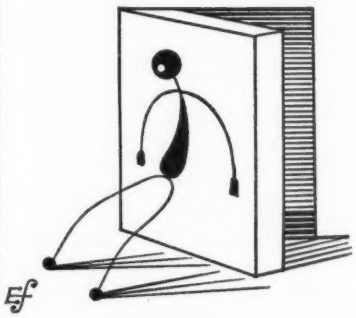
...bend...



...clamp...



...pull...



...close...

... roll, clean, sort, lift, turn, grasp and shelve. Hymatic Automation is thus invaluable in the automatic and selective transfer of parts from one process to the next, from conveyor to conveyor; in unloading one machine and loading the next; or in quick clamping to hold parts during machining. All designs of Hymatic Automation are made for specific tasks but are readily adaptable to others.

Hymatic Automation covers the whole problem—the design of the circuit—the machine—the means of control.

Hymatic Automation, therefore, has a place in your programme of productivity improvement.

Perhaps in your Works, too, there are jobs where it is possible for people to burn or cut themselves, strain or crush themselves, lose fingers or even a hand; or perhaps there are jobs for which you just cannot find people.

***In all events* CONSULT**

Hymatic Automation

THE HYMATIC ENGINEERING CO. LTD. DEPT. HA.84 · REDDITCH · WORCS.

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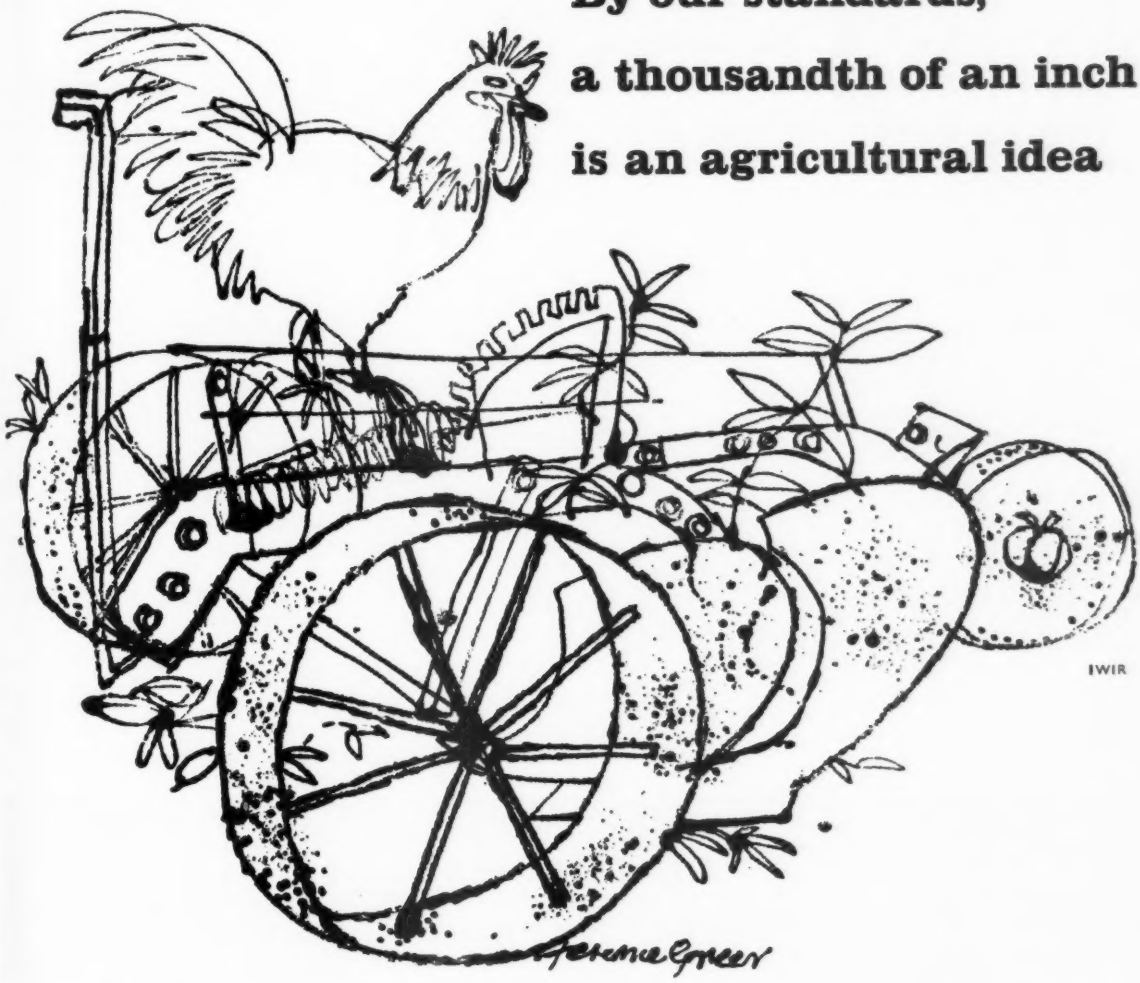
By our standards, a thousandth of an inch is an agricultural idea



You know about the man who was asked how big a 'thou' was? 'Very, very small' he said. He was asked how many there were in an inch. 'Millions of them' he said.

In this unusual factory of ours—unique in Europe, we suppose—we don't think of a 'thou' as at all small. We have had to train ourselves to take a tolerance of half a tenth in our stride, and to use on our production inspection-line a machine that will measure out-of-roundness of the order of one millionth of an inch.

But then we are in production with instruments the like of which the world has never seen before. We produce (in partnership with Minneapolis Honeywell) Inertial Quality Gyroscopes so accurate that they precess less than half a degree *per day*, so sensitive that you can use them for finding true North to within a few minutes of arc. Small wonder that we do 'sand'-blasting with bicarbonate of soda, and that a speck of dust is a calamity.

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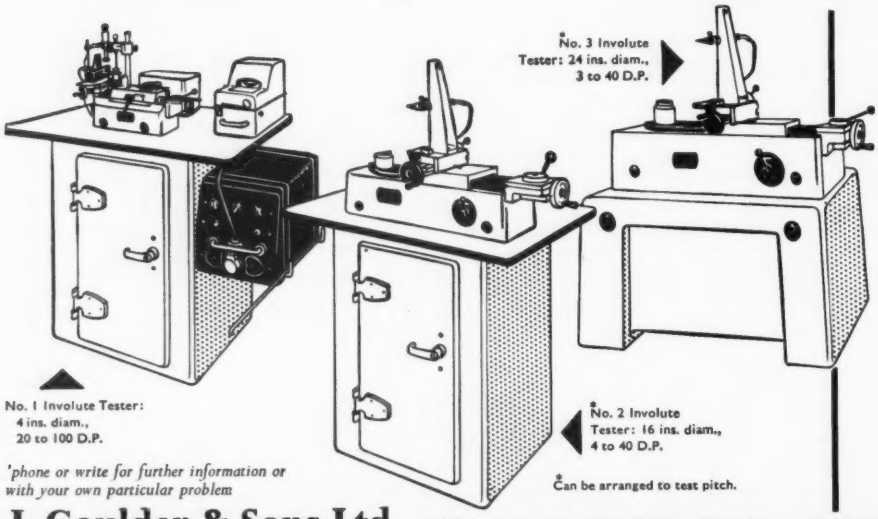
Goulder—solve all gear testing problems


No. 3 Involute Tester: 24 ins. diam., 3 to 40 D.P.
No. 1 Involute Tester: 4 ins. diam., 20 to 100 D.P.
No. 2 Involute Tester: 16 ins. diam., 4 to 40 D.P.

The Involute Testers illustrated are only part of a wide range. Goulders can supply Gear Testing Instruments for *any* type of gear which can be instrument-mounted.

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Before you order your next milling fixture contact us — we have suggested many modifications to suit customers workpieces, resulting in a saving in initial cost.

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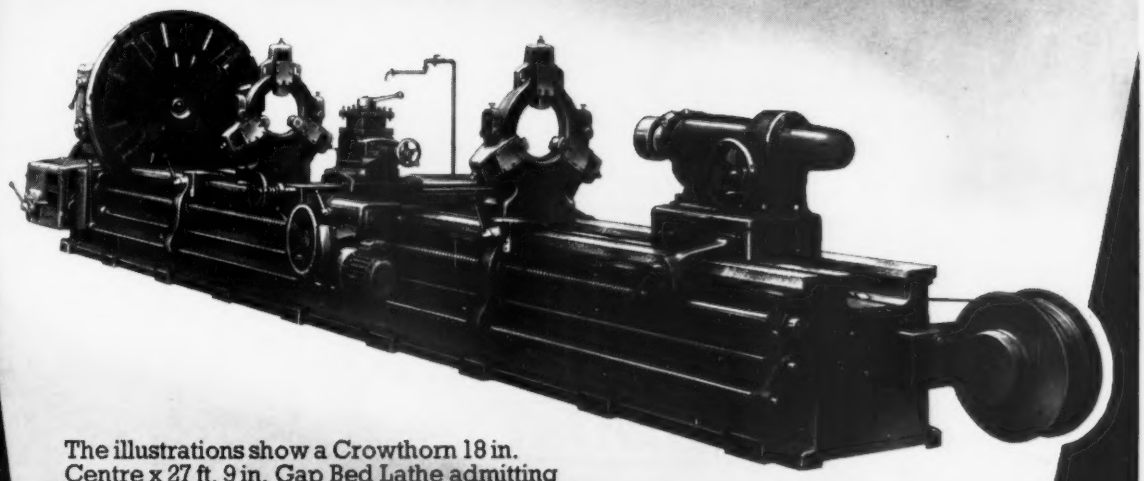
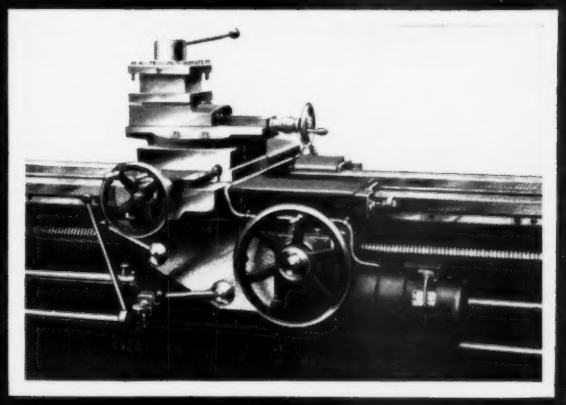
CROWTHORN

HEAVY DUTY LATHES



The illustrations show a Crowthorn 18 in. Centre x 27 ft. 9 in. Gap Bed Lathe admitting 20 ft. 6 in. between Centres and, inset, a view of the quick power traverse mechanism. The lathe is typical of Crowthorn Heavy Duty Long Bed Lathes.



some notable features of the lathe

1. Special heavy duty tailstock with built-in Timken roller bearing assembly.
2. Bed casting of very heavy section for rigidity and accuracy.
3. Quick power traverse to carriage by means of flange mounted motor and cable reel.
4. Heavy duty steadies with needle roller bearings.
5. Heavy duty grinding attachment available for mounting on cross slide in place of toolpost.
6. Taper turning attachment.
7. Micrometer dead stop.

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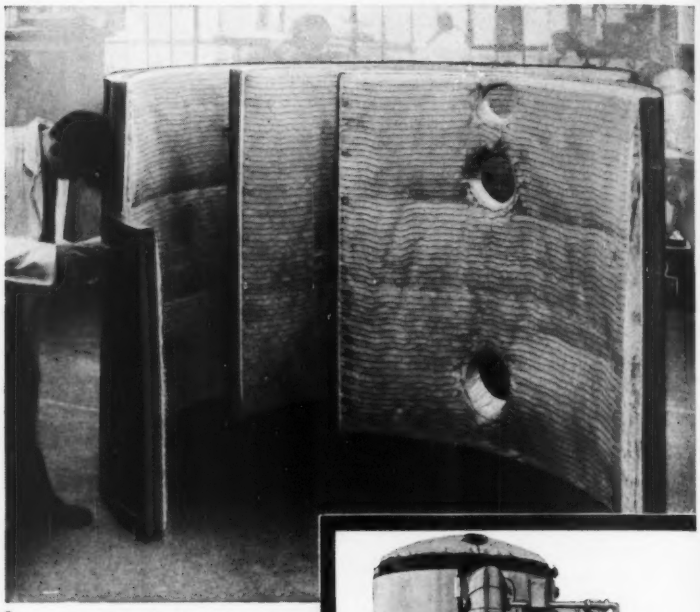
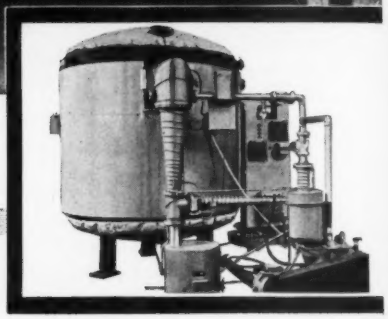
Let Isopad help you with your problem, fully illustrated literature available.



Isomantles in 120° sections. Prepared for vacuum chamber by Edwards High Vacuum Ltd.



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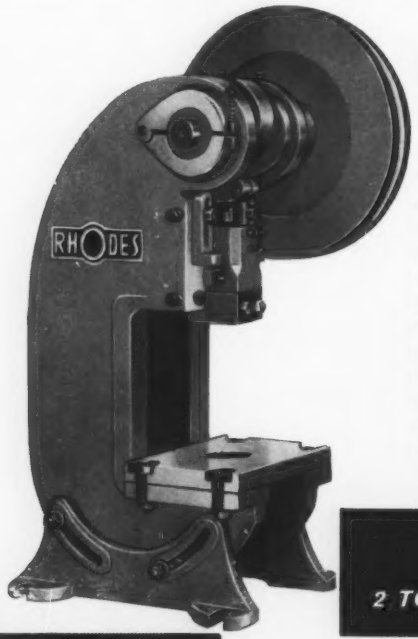

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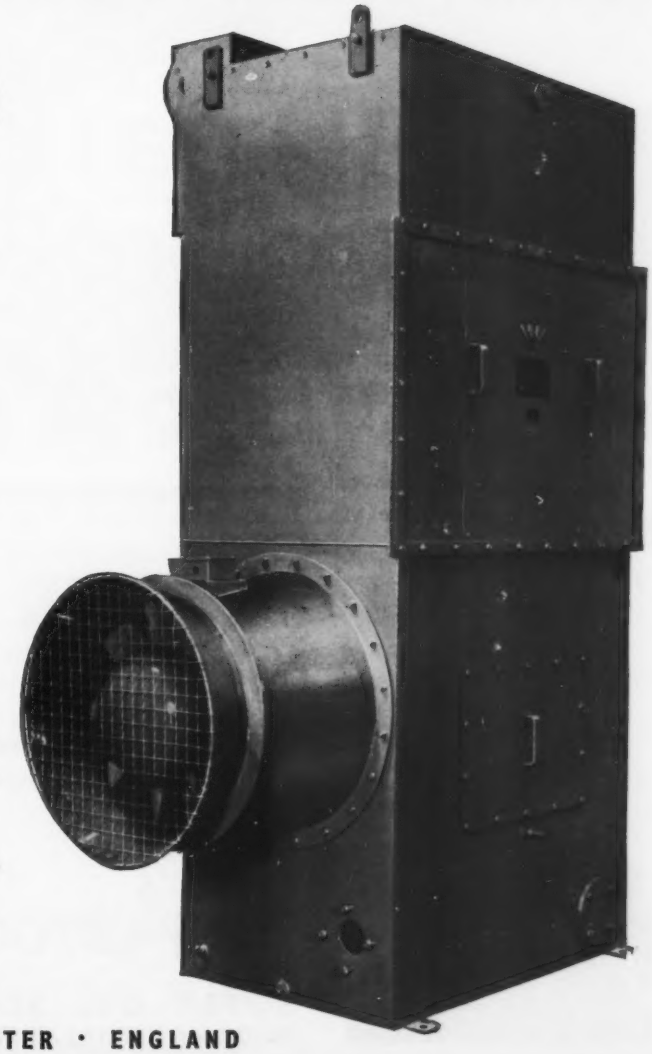

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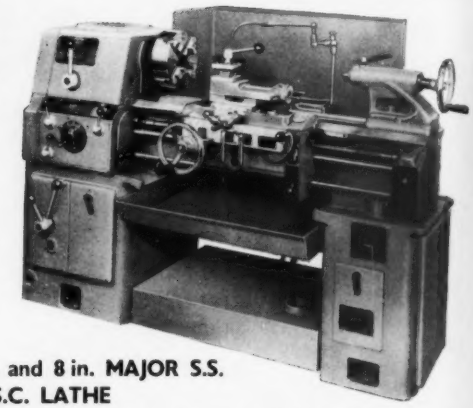

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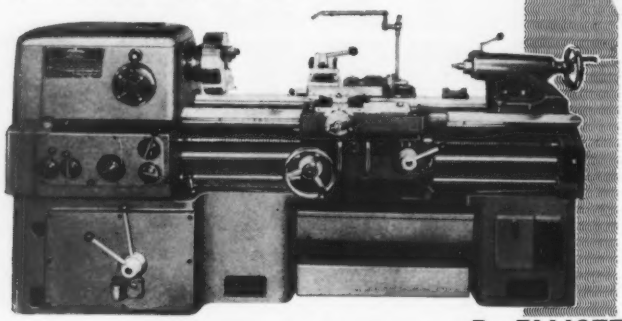

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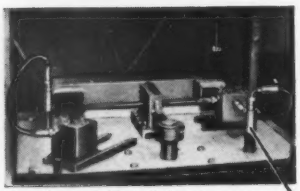

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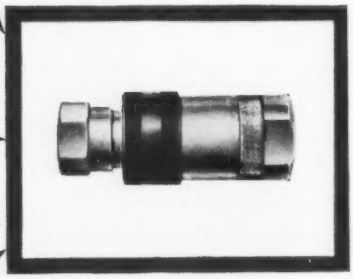

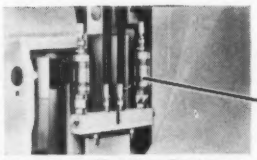

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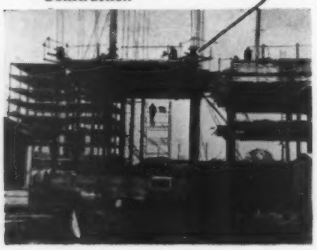

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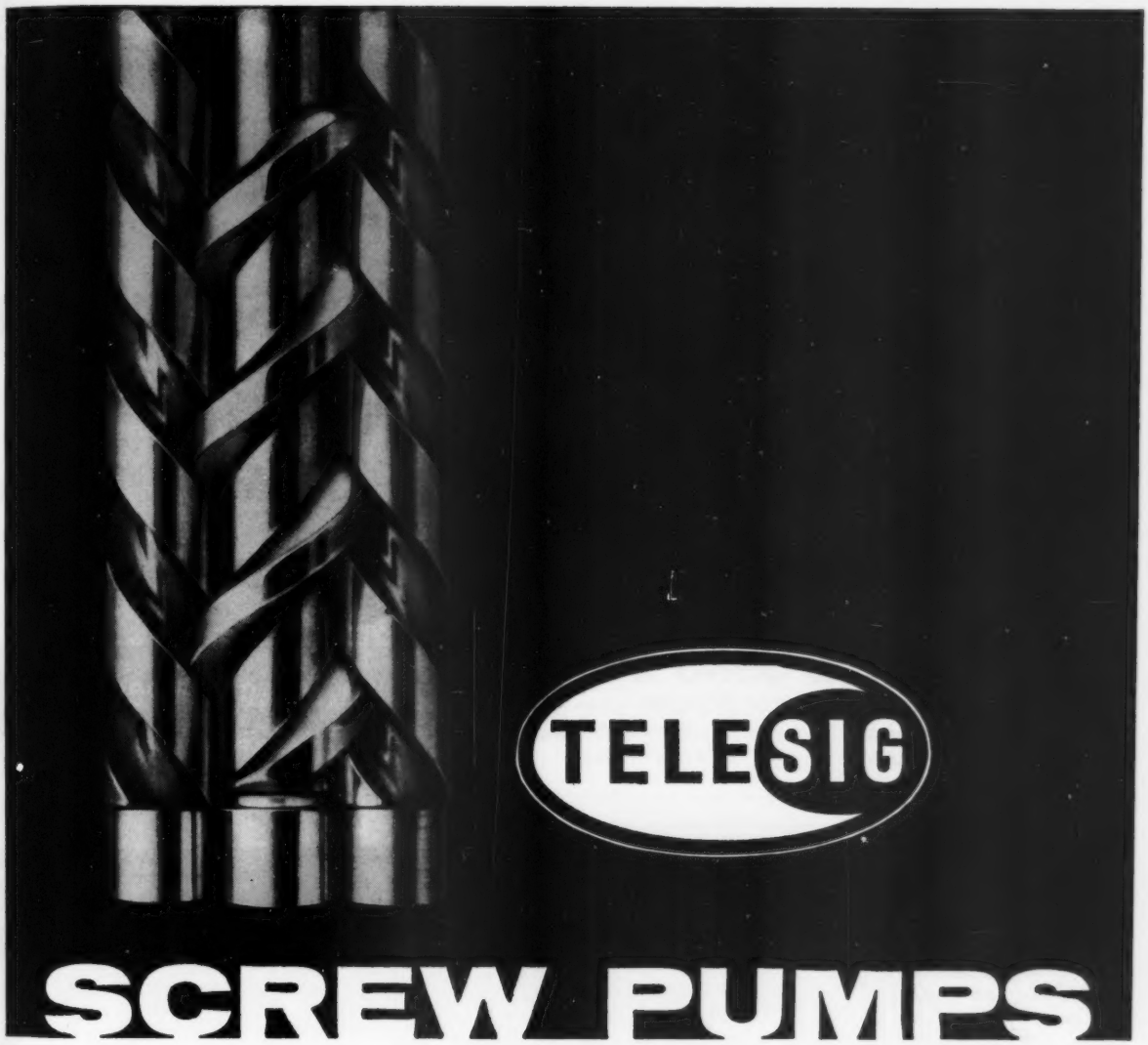

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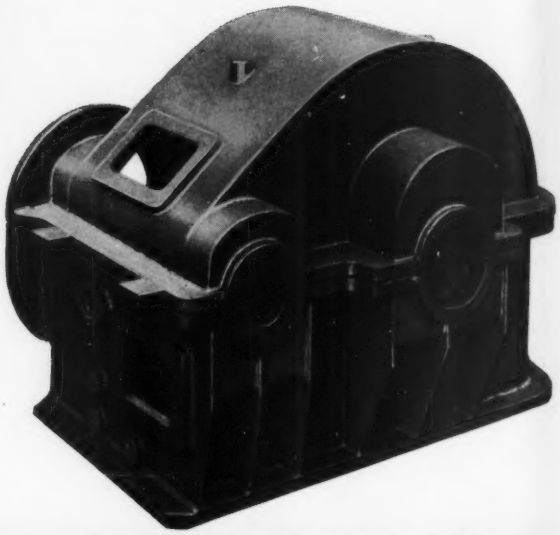

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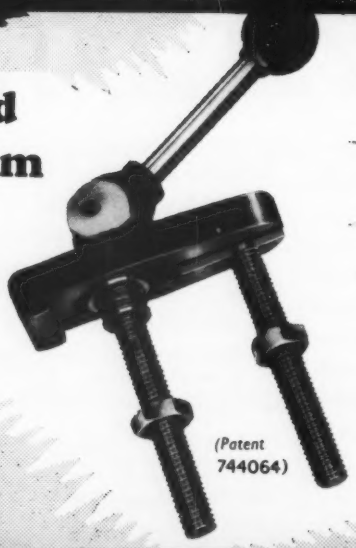

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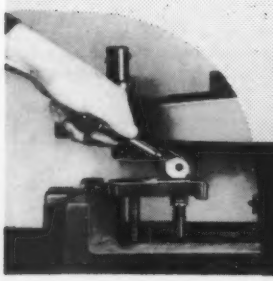

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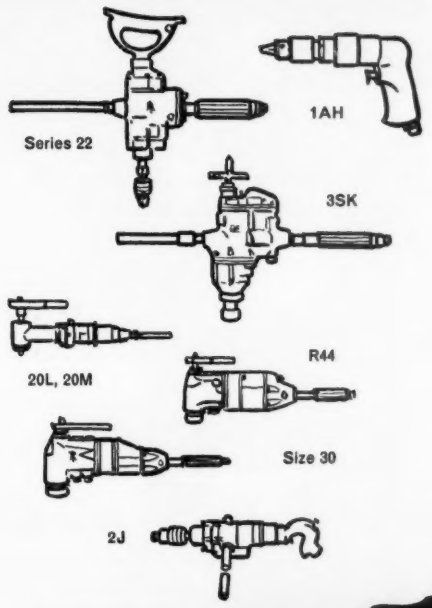

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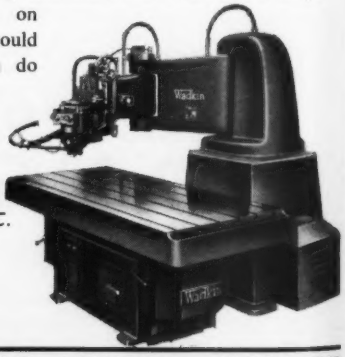

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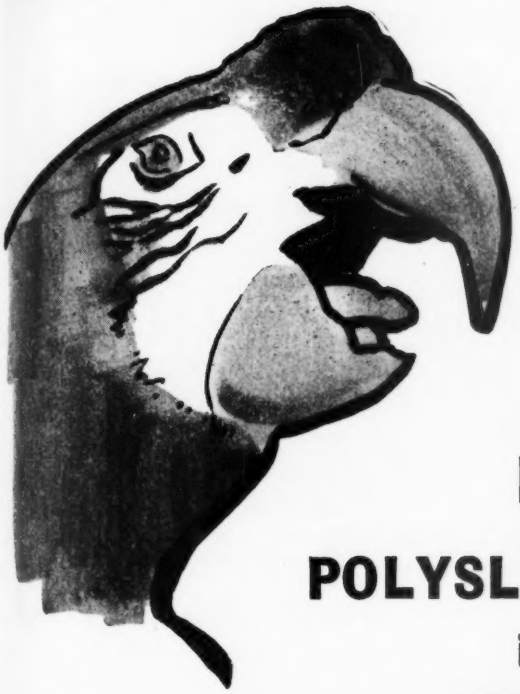

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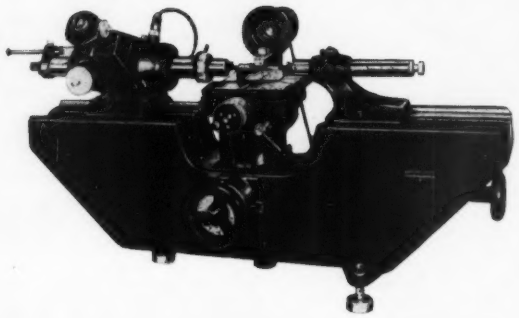

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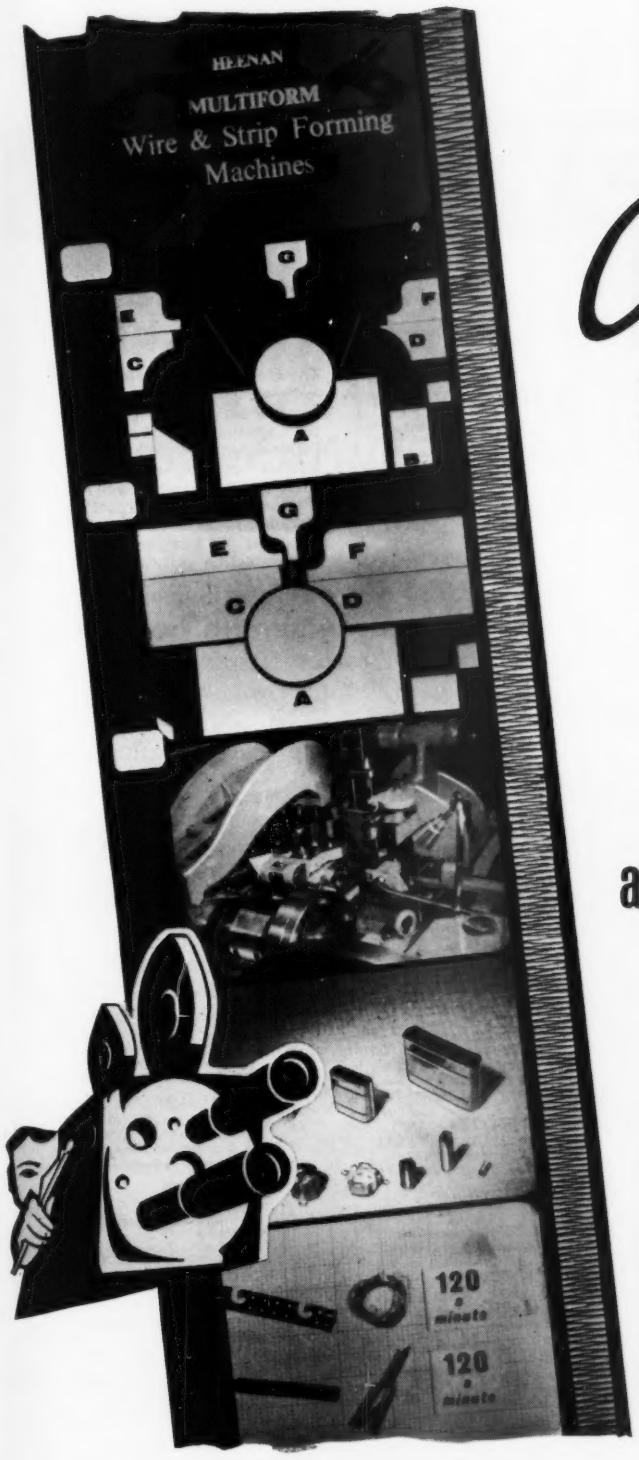

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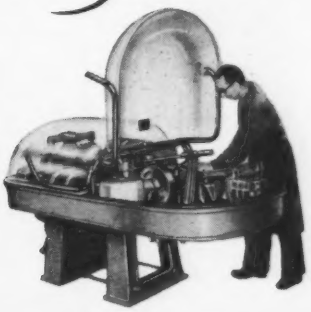

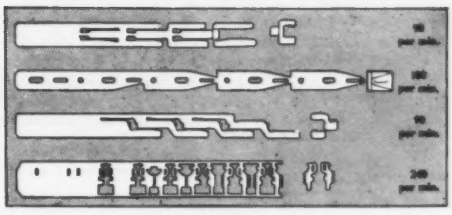

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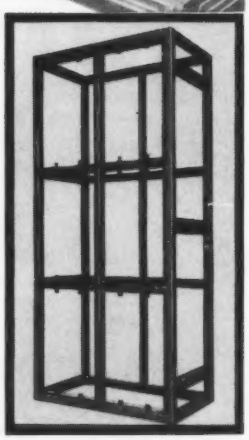

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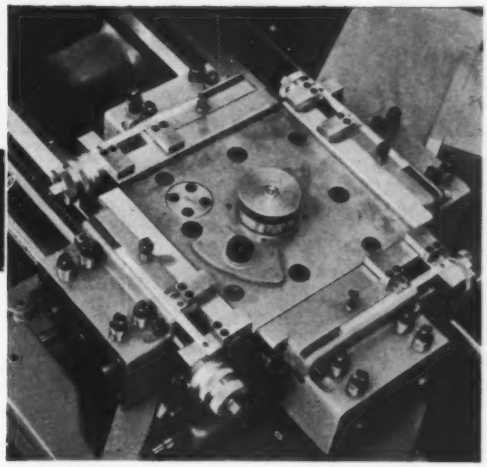
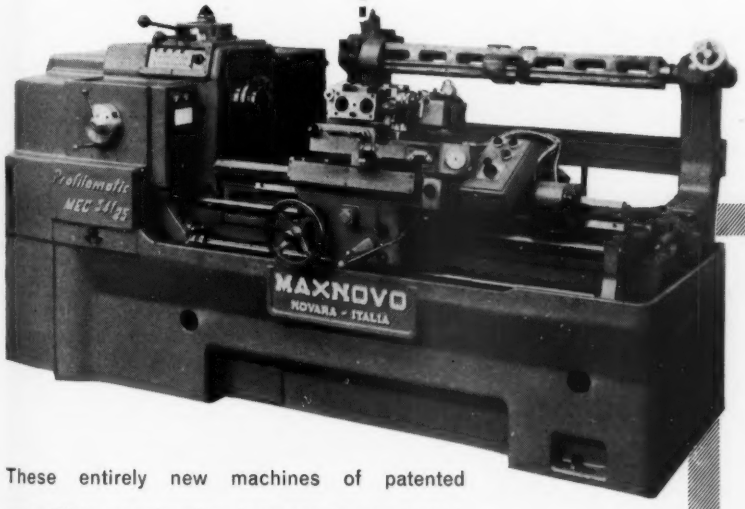


Outstanding feature is the hand-indexing, lever-clamped, square turret which is controlled by templates set on an indexing, multiple template holder; templates control ID and OD turning as well as the direction of feed.



These entirely new machines of patented monolithic construction incorporate corrugated, double-wall bed with integral hardened and ground ways; hardened and ground gears and shafts; anti-friction bearings which are used throughout, permitting heavy cuts, fast cutting speeds with a high degree of accuracy. The Model M.E.C. 25-341A has fully automatic cycle.

Brief Specification.

Swing dia. over bed	20⅞ in.
No. of spindle speeds	16 or 32
No. of feeds	8 or 16
Speed range (16)	50-1000 r.p.m.
	100-2000 r.p.m.
(32)	50-2000 r.p.m.
Drive Motor—standard	12-15 h.p.
—heavy duty	18-22 h.p.

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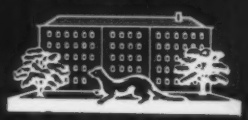

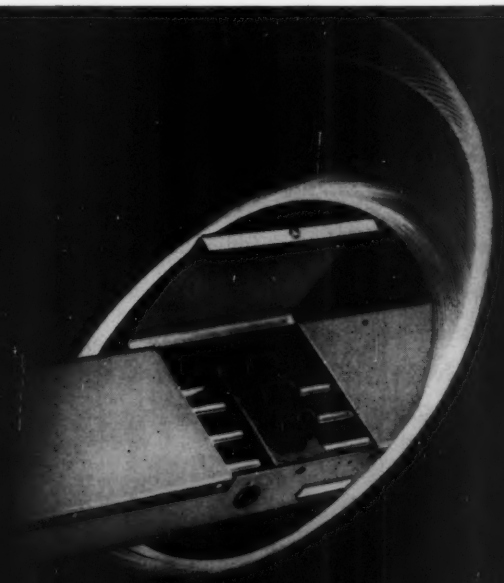

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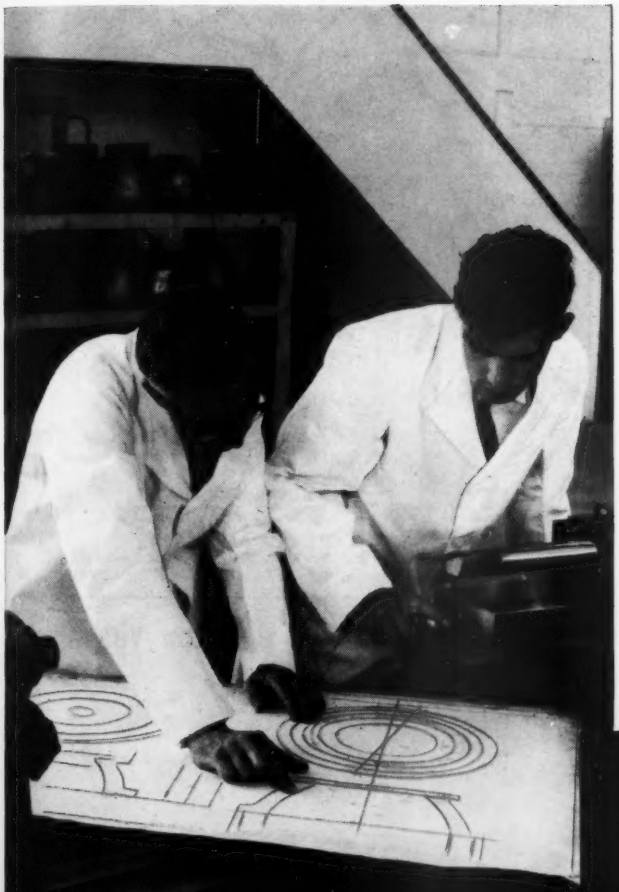
Workshop angle and D.O. viewpoint



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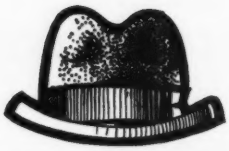
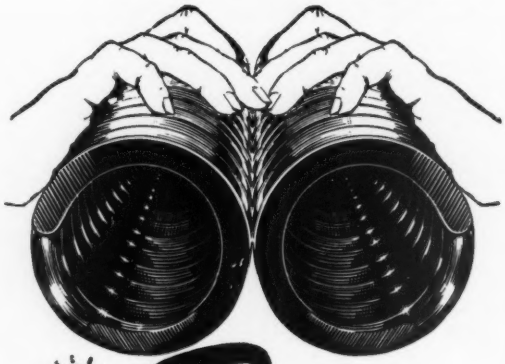


Looking in the right direction



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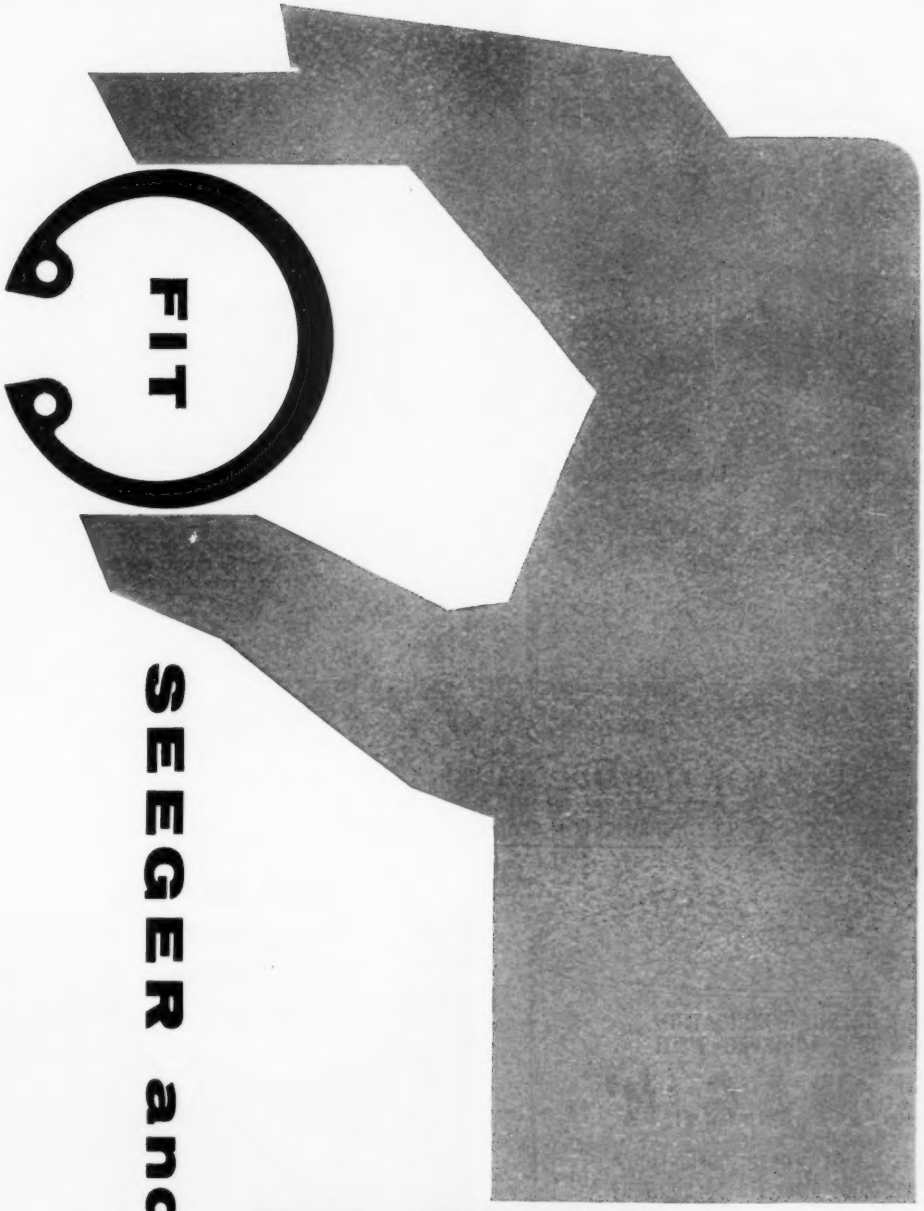

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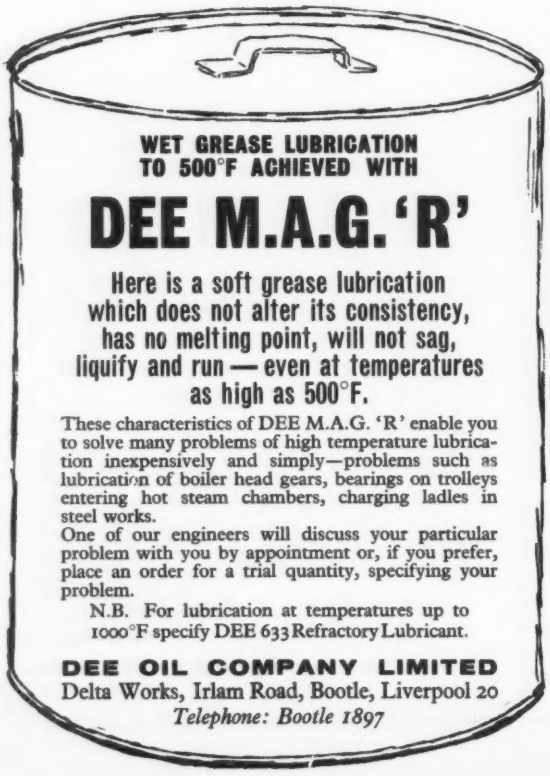

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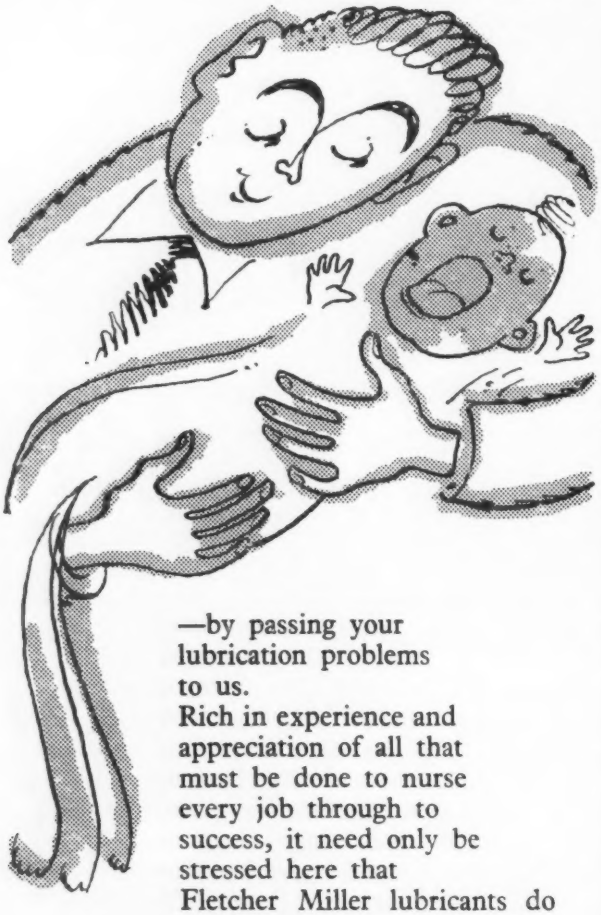

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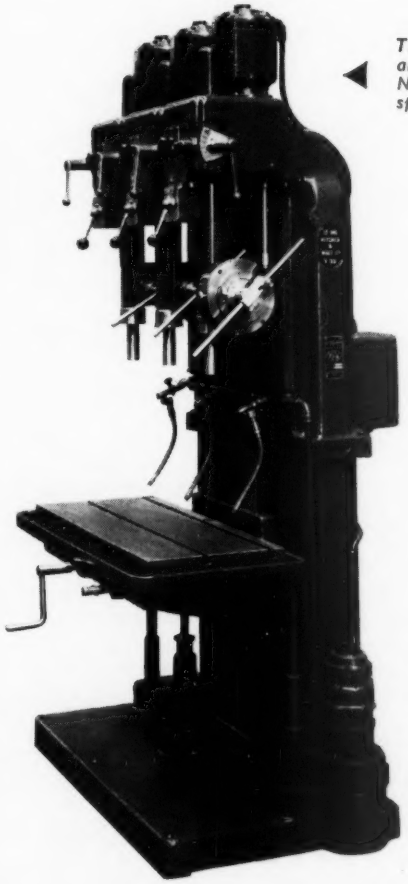

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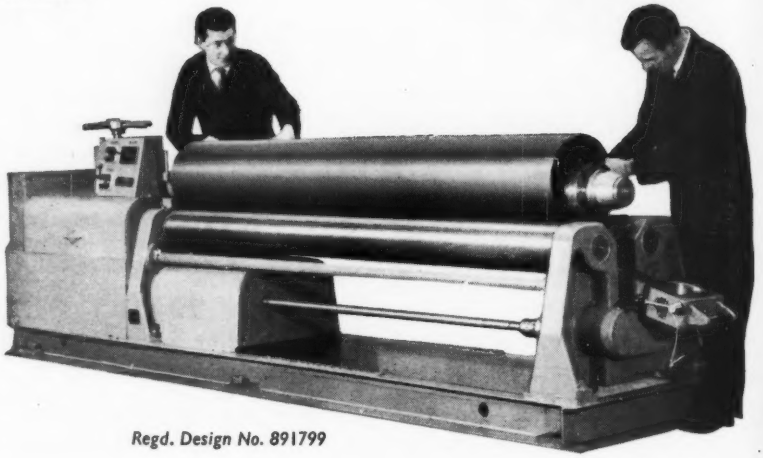

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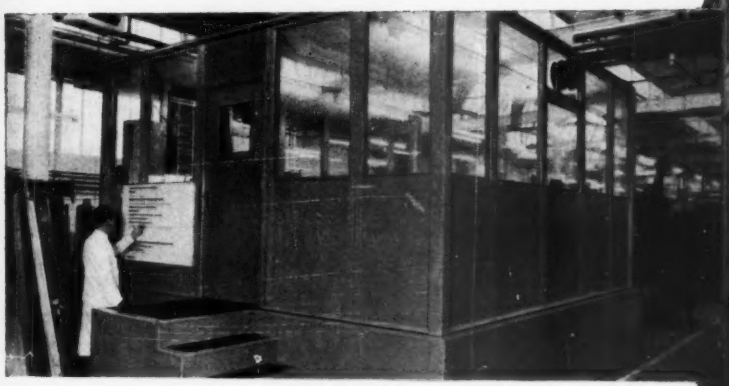

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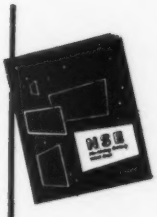

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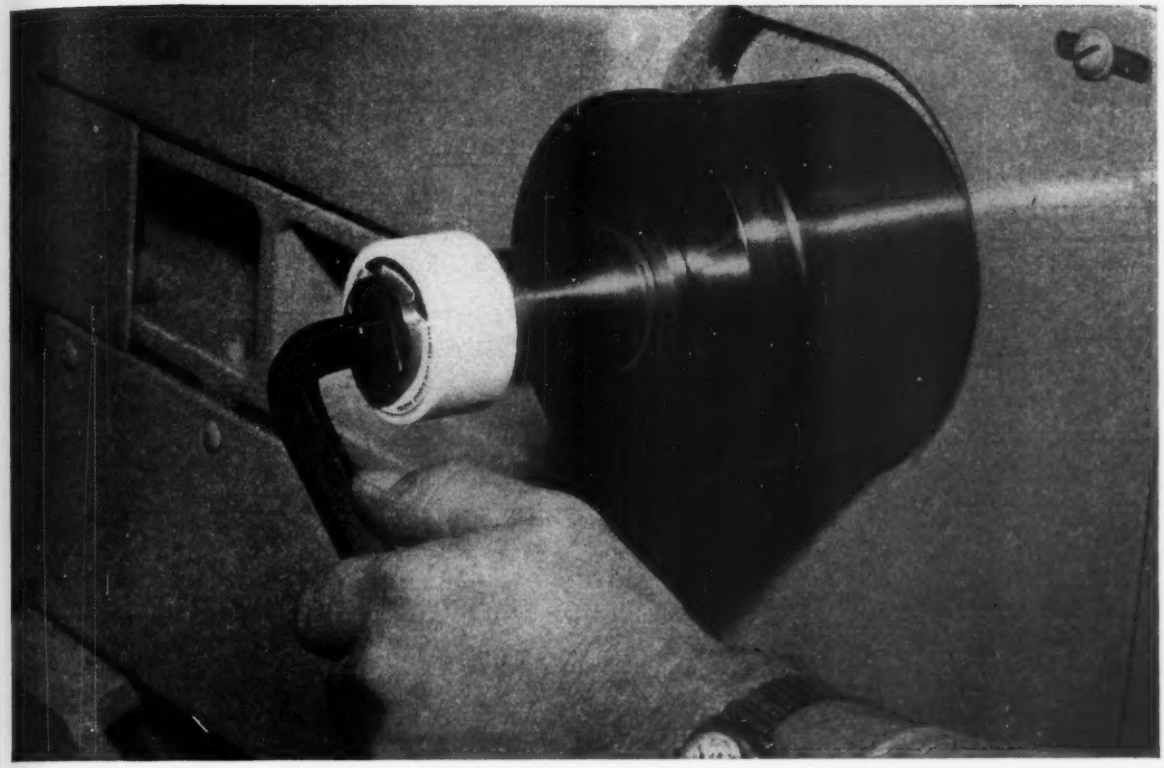

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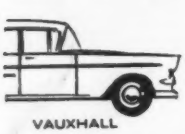
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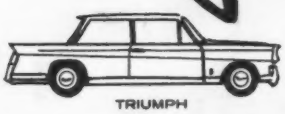
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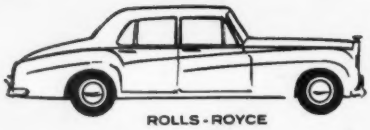
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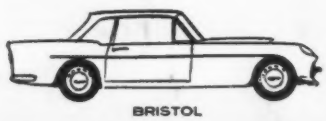
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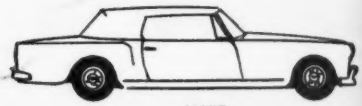
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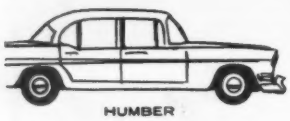
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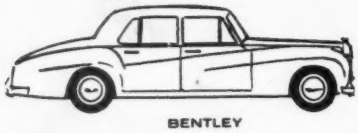
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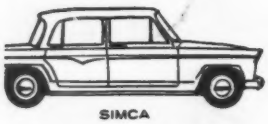
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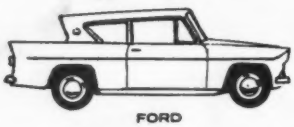
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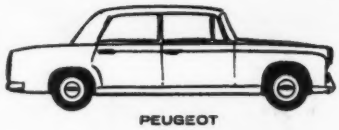
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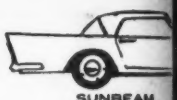
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